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Improving the quality of adaptive learning support provided by kindergarten teachers in play-based mathematical learning situations

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ABSTRACT

Adaptive learning support is a key element of high quality preschool education and includes the planning of learning situations and teacher–child interactions. The provision of effective adaptive learning support in kindergarten is challenging. This longitudinal experimental study examined the impact of two professional development programs on 132 kindergarten teachers. One program focused on teacher–child interactions (micro-adaptive learning support), the other on planning, preparation, and reflection (macro-adaptive learning support). Each program had a positive impact on the quality of the specific type of adaptive mathematical learning support provided by kindergarten teachers, macro or micro, it was designed to improve.

KEYWORDS

Kindergarten teachers; macro-adaptive learning support; micro-adaptive learning support; professional development; play-based mathematical learning

1. Introduction

Targeting adaptive learning support so that it falls within a child's zone of proximal development is a key goal of preschool education (Sylva et al. 2010). According to Vygotsky (1978), children learn effectively if they are guided from the *level of actual development* into the *zone of proximal development* and on to the *level of potential development*. Learning support in preschools must therefore be very adaptive (Vaughn and Parsons 2013).

Learning in preschool institutions tends to be informal and is often embedded in natural and play-based learning situations (e.g. Gasteiger, Brunner, and Chen 2021; Walsh, McMillan, and McGuinness 2017). Adaptive support during teacher–child interactions is critically important for fostering the desired academic and socio-emotional outcomes in such situations (e.g. Gasteiger 2015; Walsh, McMillan, and McGuinness

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2017). New curricula with an increased emphasis on the academic progress of younger children which are now being implemented in many countries require preschool teachers to prepare more and increase their monitoring and assessment of children's learning (DeLuca, Pyle, and Lapointe-McEwan 2020; Pyle and DeLuca 2017). Because this emphasis on academic learning is new for preschool teachers in some countries – particularly in German speaking countries – it merits special attention (Gasteiger, Brunner, and Chen 2021). This paper focuses on the learning support provided in kindergarten – preschool for children aged 4–6 in German speaking countries.

Adaptive learning support includes both the support provided during a learning situation and the preparation for and reflection after the provision of the support (Hardy, Decristan, and Klieme 2019; Parsons et al. 2018). We distinguish between micro- and macro-adaptive learning support during these different phases of teaching (Corno and Snow 1986; Hammond and Gibbons 2005; Schön 1983). In the context of kindergarten micro-adaptive learning support can be defined as teacher–child interactions during the learning situation, and macro-adaptive learning support as the planning, preparation, and reflection phases before and after. The two types of adaptive learning support have different competence requirements (Lindmeier 2011; Lindmeier et al. 2021; Knievel, Lindmeier, and Heinze 2015): Micro-adaptive learning support entails being able to respond spontaneously to the child, while macro-adaptive learning support involves planning the learning situation and reflecting on it afterwards.

Research focusing on micro-adaptive learning support confirms that it is challenging for kindergarten teachers to provide high quality adaptive learning support during learning situations (e.g. Cabell et al. 2013; König 2009; Siraj-Blatchford et al. 2002). Studies have shown that kindergarten teachers have difficulty adapting and planning learning situations in response to diagnoses (Wullschleger 2017; Bruns 2014). There is a disconnect between the significance attributed to high quality adaptive learning support by researchers and its observed quality in kindergartens. It is therefore very important that kindergarten teachers' professional development focuses on improving adaptive learning support skills.

This study uses an experimental design with a play-based mathematics activity to examine whether two professional development programs, one focusing on micro- the other on macro-adaptive learning support, can each separately increase the quality of the respective adaptive support provided by kindergarten teachers.

1.1. Adaptive learning support in kindergarten

Adaptation in the context of teaching and learning is the fit between the needs of the learner and instruction by the teacher (Vaughn and Parsons 2013). Parsons et al. (2018, 230) define adaptive instruction as follows: '[…] teachers constantly monitor classroom proceedings, observing student learning, motivation and behavior, which serve as stimuli or antecedents for teachers to adapt their instruction.' We distinguish between micro- and macro-adaptive learning support based on the following concepts: Corno and Snow's (1986) differentiation between macro-adaptation (longer term, month-to-month teacher and program-level decisions) and micro-adaptation (moment-to-moment adaptations), Schön's (1983) concept of reflection-on-action (reflecting on students' needs before and after a learning situation) and reflection-in-action (changing

planned actions in the moment), and Hammond and Gibbons (2005) differentiation between macro- (pre-planned) and micro-scaffolding (contingent).

1.1.1. Micro-adaptive learning support

Micro-adaptive learning support focuses on the teacher's responses (Corno and Snow 1986) during teacher–child interactions 'in the dynamic unfolding of lessons' (Hammond and Gibbons 2005, 20). La Paro, Pianta, and Stuhlman (2004) defined the quality of these interactions in the Classroom Assessment Scoring System (CLASS) using three criteria: two focus on social and emotional learning support (management in the sense of monitoring the children and preventing disruptive behavior and emotional climate) and one is subject-specific (instructional support). CLASS has been used to assess pedagogical process quality in preschool (Hardy and Steffensky 2014).

Management includes handling and preventing disturbances to ensure learners are engaged and attentive (Freiberg, Oviatt, and Naveira 2020). In kindergarten, this dimension refers to the structuring of daily routines or guiding children (Kuger and Kluczniok 2008). *Emotional climate* refers to the emotional connection of the kindergarten teacher to the children. It includes supportive, trusting, and appreciative behavior occasioning socio-emotional support (Kuger and Kluczniok 2008). *Instructional support* focuses on '… the degree to which a teacher promotes higher-order thinking and problem solving … how teachers engage children in activities and facilitate activities so that the learning opportunities are maximized' (La Paro, Pianta, and Stuhlman 2004, 414). This means challenging the children in domain-specific learning situations (Kuger and Kluczniok 2008) and using support strategies such as giving hints or asking cognitive-activating questions (Wullschleger 2017). Instructional support also encompasses the technical language for a subject. In this study we focus on mathematical learning and so also consider mathematical language, which is an important aspect of children's learning (Klibanoff et al. 2006; Swaminathan and Trawick-Smith 2020).

Research on early childhood education has shown that providing micro-adaptive learning support is challenging. Studies of teacher–child interactions in everyday situations have found that very few of the interactions are adaptive (Cabell et al. 2013; König 2009; Siraj-Blatchford et al. 2002). These findings also seem to apply to mathematical learning situations (Cabell et al. 2013). Bruns (2014) investigated mathematics related interactions in a quasi-experimental study in Germany and Switzerland. She investigated the adaptive mathematical learning support provided by 31 kindergarten teachers and found that most teachers provided inadequate support and none exhibited the highest level of competence. Tournier (2017) examined the cognitive activation skills of kindergarten teachers in science, free play, and mathematical learning situations. She found that cognitive activating hints and questions were rarely given in a free play or mathematics learning context.

1.1.2. Macro-adaptive learning support

Macro-adaptive learning support includes the planning and preparation before learning situations (e.g. considering students' prior knowledge, selecting and sequencing tasks) (Hammond and Gibbons 2005) and the reflection afterwards about what occurred during the learning situation (Schön 1983). The activities must suit the children's level of development, which requires sophisticated knowledge about children's *level of*

actual development and therefore requires diagnostic practices (Ruiz-Primo and Furtak 2007). Many assessment techniques are suitable for gathering information on the learning processes and abilities of kindergarten-age children (e.g. observations, evaluation of work samples). Such evaluation is a continuous and dynamic process of collecting, synthesizing, and interpreting information (Brassard and Boehm 2007; Epstein et al. 2004; Gasteiger 2015).

Few studies combine an assessment of the quality of macro-adaptive support with an assessment of micro-adaptive support. Wullschleger (2017) conducted a video- and interview-based analysis of micro- and macro-adaptive learning support in play-based mathematical learning situations. Although the kindergarten teachers were able to diagnose children's mathematical competence, they often struggled to tailor their learning support in the subsequent interaction. The teachers rarely used their diagnostic knowledge when planning a mathematical game session. Similarly, Bruns (2014) found that only one third of the kindergarten teachers in her study defined mathematical learning goals and the mathematics activities offered did not align with the learning goals.

Although there is not a great deal of research on adaptive learning support in play-based mathematical situations in kindergarten, these findings indicate that there is a gap between the significance attributed to micro- and macro-adaptive learning support and its observed quality. To address this gap, this study examined whether the instructional quality of macro-adaptive learning support and subject related micro-adaptive learning support can be improved through targeted professional development programs.

1.2. Professional development of kindergarten teachers matters

To enhance the quality of adaptive learning support, it is important to have information about the professional development of kindergarten teachers. Teacher professional development takes many forms, such as in-service training, coaching, and professional development courses (Desimone 2009; Son et al. 2013). Research has shown that such programs are effective tools for improving early childhood education. Fukkink and Lont (2007) conducted a meta-analysis on the effects of specialized training on caregivers' competences, looking at professional knowledge, attitudes, and skills related to teacher–child interactions. They found that specialized training had a significant positive effect on the caregivers' pedagogical competence. These results are in line with the meta-analysis conducted by Werner et al. (2016).

There is limited research into the effectiveness of professional development programs focusing on mathematics in early childhood education. Vick Whittaker et al. (2016) investigated the effects of a mathematics and science curriculum combined with professional development support on the quality of 42 pre-kindergarten teachers' classroom interactions. They found that targeted curricula combined with embedded professional development support had a positive effect on the quality of teachers' classroom interactions. Similarly, Bruns, Eichen, and Gasteiger (2017) created a professional development course focusing on mathematical learning in kindergarten and tested its effects on 99 early childhood teachers. The study found a small positive impact on pedagogical content knowledge and a significant change in unfavourable personal beliefs (decrease in static orientation towards mathematics). Focusing on math talk, Swaminathan and Trawick-Smith (2020) trained 13 teachers and assistants with minimal levels of education

in math talk during free play. The authors found a significant increase and diversification in math talk over a five-month period.

This research overview shows that it is possible to enhance the professional development of a kindergarten teacher's ability to support high-quality learning.

2. Materials and methods

2.1. Enhancing adaptive learning support – the study

The purpose of this study was to examine whether kindergarten teachers' micro- and macro-adaptive mathematical learning support could be separately enhanced. The focus was on instructional support, in this case subject-related mathematical learning support. Socio-emotional characteristics were also considered since they are also important for micro-adaptive learning support. The study investigated the following research question:

How do two professional subject-related development programs, one focusing on micro- and the other on macro-adaptive mathematical learning support, improve the quality of micro- and macro-adaptive support provided by kindergarten teachers in a play-based learning situation?

Given the theoretical and empirical evidence, we hypothesized that each program would enhance the quality of kindergarten teachers' mathematical learning support in its respective area. Because the focus of the program was on subject-specific instructional support, no effect on the quality of social-emotional learning support was expected.

2.2. Participants

The study was carried out in Switzerland and Germany. In Switzerland, kindergarten is part of elementary school. The kindergarten teachers are obliged to follow a curriculum that includes mathematical learning goals. For more than a decade all prospective kindergarten teachers have had to attend academic professional training. In Germany kindergarten is not a part of the public schooling system. There are curricula but they are neither as targeted nor as prescriptive as the curricula in Switzerland. Most kindergarten teachers attend a vocational school in Germany, although an academic education route is also possible (Gasteiger, Brunner, and Chen 2021).

A total of 132 kindergarten teachers participated in the study, 65 from the German-speaking part of Switzerland and 67 from Germany (Kiel and Vechta). On average professional experience was 13.5 years ($SD = 10.4$, $min = 0$, $max = 41$). Most participants in Germany ($n = 60$) and about half of the participants in Switzerland ($n = 31$) had been educated in a vocational training setting. (Table 1)

2.3. Procedure

The study was designed as a controlled longitudinal experiment. The project was approved by the ethical committee of the University of Zurich and the kindergarten teachers and their parents gave written consent. The quality of micro- and

Table 1. Study participants.

Participants	Country		Kindergarten teachers	Male
	Switzerland		65	0
	Germany		67	7
	Total		132	7
Years of professional experience	Country	Mean (SD)	Min.	Max.
	Switzerland	12.46 (9.43)	0	35
	Germany	14.61 (11.31)	1	41
	Total	13.54 (10.44)	0	41
Professional training	Country		Academic	Vocational
	Switzerland		31	34
	Germany		7	60
	Total		38	94

macro-adaptive learning support was assessed before (pre-test, t1) and after the intervention (post-test, t2; Figure 1). After the pre-test, all participants attended a briefing session (3 h) during which they were introduced to a box of games proven to promote children's numerical development (Hauser et al. 2015). The participants were told to use these games three times per week for about 20–30 min each, for six months.

For the professional development phase, the kindergarten teachers were randomly assigned to three groups: One was allocated to a program to improve the quality of micro-adaptive learning support ($group^{MICRO}$), one to a program for improving macro-adaptive learning support ($group^{MACRO}$), and a third served as a control group ($group^{CONTROL}$).

2.3.1. Assessment of micro- and macro-adaptive learning support

The quality of micro-adaptive learning support was examined using video recorded semi-standardized learning situations during a play-based mathematical activity. For each kindergarten teacher, the support he/she offered in two situations (approximately 15 min each) with a group of 2–3 children was recorded twice. At t1, all groups used the easy-to-understand 'gold coins' game (Schmassmann and Moser Opitz 2007), a board game where children use dice, count objects, and link numbers and quantities. At t2, the kindergarten teachers had to choose two of the 10 board and card games that all participants

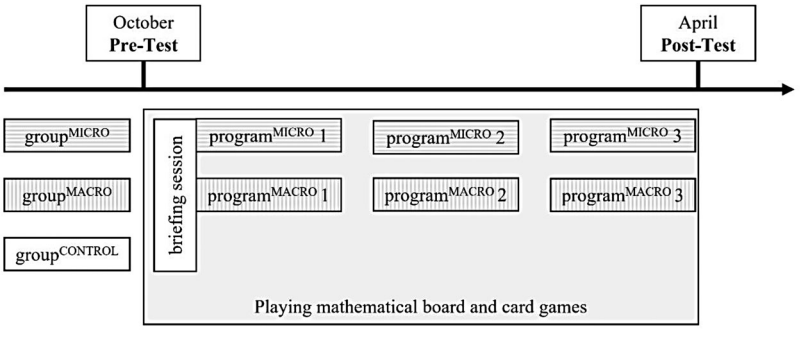

Figure 1. Study design.

had been given at the briefing session. Most of these games were more complex than the 'gold coin' game used at t1 (greater mathematical demands, more complex rules), and therefore demanded more adaptive support.

Macro-adaptive support quality is difficult to rate objectively using video observation since it is dependent on subjective factors like the teacher's knowledge of their children's abilities. We used structured interviews to infer whether the observed play-based situation was adaptively planned and purposefully used to foster mathematical learning. These interviews took place directly after the video recordings.

2.3.2. Professional development programs

After the briefing session both groups attended three training sessions which each lasted three hours. Everyone received the same information about the numerical development of kindergarten children, which was based on the model proposed by Krajewski and Schneider (2009).

Group^{MICRO}: The focus of this program was managing, supporting, and activating the children in play-based mathematical learning situations. It provided strategies for explaining, giving hints, asking cognitively activating questions, dealing with mistakes, structuring solution processes, illustrating mathematical content, and using mathematical language (Wullschleger 2017). The strategies were illustrated using video examples and role play and the participants were asked to apply them between the training sessions.

Group^{MACRO}: This program emphasized the adaptive planning and preparation of and reflection on learning situations. Diagnosing the mathematical competences of children in play-based situations was practised with the help of video clips. The difficulty level of the games selected and their potential for mathematical development was analysed as an important prerequisite for adaptive planning. Between the training sessions the participants were asked to practice diagnosing numerical competence.

Group^{CONTROL}: The control group only attended the briefing session and received the box of games and written instructions. The teachers were invited to join the program after the post-test.

All participants – children and teachers – had access to a program to enhance children's mathematical learning.

2.4. Measures

A researcher-developed instrument was used to assess the quality of micro- and macro-adaptive learning support (Meier-Wyder et al. 2022). The instrument, derived from existing instruments CLASS (Pianta, La Paro, and Hamre 2008), ECERS R (Harms, Clifford, and Cryer 2005), and KES-R (Roßbach et al. 2018), was specifically designed for a mathematical learning context. It was expanded with items developed by the research group that focused on macro-adaptive learning support.

2.4.1. Quality assessment of micro-adaptive learning support

Four items provided information about micro-adaptive learning support (Table 2), two items focused on subject-related support, and two items addressed social-emotional learning support.

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

	Item	Indicator	Examples
Social-emotional learning support	Emotional warmth	• Non-verbal: benevolent 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 directing attention to the game • Preventing disturbances; appropriate regulation of disturbances	• The rules of the game are established and made explicit.
Subject-related learning support	Adaptive learning process stimulation	• Fit between the actions of the kindergarten teacher and the mathematical activities of the children • Promotion into the zone of proximal development through targeted explanations or hints, challenging questions, etc.	• How can you determine as quickly as possible the number of eyes on your 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. The maximum score for each item was 4, the minimum score 1.

Four learning situations with each teacher were recorded on video, two at t1 and two at t2. The video clips were then divided into 5-minute intervals and each of the intervals was assessed for its support quality. The quality score for t1 was calculated using the mean of the ratings of all intervals of t1. The quality score for the data for t2 was calculated using the mean values of the ratings of all intervals of t2.

2.4.2. Quality assessment of macro-adaptive learning support

The quality of *macro-adaptive learning support* was assessed using data from an in-depth interview conducted immediately after the video recordings. The interviews covered the

Table 3. Rating instrument for assessingthe quality of macro-adaptive learning support.

Item	Indicator	Example interview questions
Planning of 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.	• Which mathematical competence did you expect from each child?
Reflection	• Critical reflection on the goals and planning of the activity and learning support provided.	• At which points was it particularly important to support 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 individual 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. The maximum score for each item was 4, the minimum score 1.

deliberations of the teacher when planning, implementing and then reflecting on the game situation. The rating of the interview data corresponded to specific interview questions. See Table 3 for a synopsis of the items.

There were two interviews with each kindergarten teacher; one reviewed the two video recordings at t1 and one the recordings at t2. For each measurement point, one score was given for each item.

2.5. Data analysis

2.5.1. Quality of the instrument and group comparisons

The ratings were carried out by trained research assistants, two from Switzerland and two from Germany. Fifteen percent of the data was rated by all raters. First, the reliability and validity of the instrument was assessed. The interrater reliability and variance components were examined using the EduG program for the generalizability of studies (Swiss Society for Research in Education Working Group 2010). The *social-emotional learning support* and *subject-related learning support* variables were each measured using two items. Internal consistency was assessed using the Spearman-Brown Formula (Eisinga, te Grotenhuis, and Pelzer 2013). Cronbach's alpha was computed for the *macro-adaptive learning support* construct. To investigate the dimensionality of the scales, confirmatory factor analyses for a three-factor model were calculated with the software R for t1 and t2 using the lavaan statistical package (Rosseel 2012, Version 06-3). The three factors were s*ubject-related micro-adaptive support*, *social-emotional micro-adaptive support*, and *macro-adaptive learning support*. As the normality assumption was partially violated, the analyses were carried out using the Maximum Likelihood Robust Estimator (MLR Estimator). An error correlation was allowed for the *planning of learning situation* and *diagnostic knowledge* items since they were often discussed together in the interviews.

Second, we tested to see if there was a difference in the quality of learning support provided at t1 by group^{MICRO}, group^{MACRO} and the control group. These group difference tests were carried out with ANOVAS using SPSS Statistics 25 software.

2.5.2. Improvement in the quality of adaptive learning support

Three separate sequential regression analyses were conducted to evaluate how the two professional development programs improve the quality of micro- and macro-adaptive learning support. We chose this approach because the pre-test and the post-test situations were different: At t1, all groups used the gold coin game, whereas at t2 the teachers had to choose two different games from 10 that varied in mathematical content and difficulty, making adaptive learning support at t2 more demanding than at t1.

The dependent variables in the three regression analyses were:

- subject-related micro-adaptive learning support at t2
- social-emotional micro-adaptive support at t2
- macro-adaptive learning support at t2

Manifest variables were used in the analyses because there were only two items of micro-adaptive learning support. In a first step, the professional development program

was inserted using two dummy variables indicating participation in group^{MICRO} or group^{MACRO}. The control group was identified as the reference category. In a second step, the quality assessment of the respective learning support variable at t1 was inserted. In step 3, control variables were included: the country in which the teachers are employed, the professional training path (dummy variable: academic vs. vocational), and the years of professional experience. We used SPSS Statistics 25.

3. Results

3.1. Reliability and validity of the rating instrument

Interrater reliability was high at t1 (G-coefficients between .81–.95) and t2 (G-coefficients between .76–.95).

At t1 the Spearman-Brown coefficients were .79 for subject-related micro-adaptive support items and .79 for social-emotional micro-adaptive support. Cronbach's alpha for macro-adaptive learning support was .66. At t2, the Spearman-Brown coefficients were 0.81 for subject-related micro-adaptive support items and .72 for social-emotional micro-adaptive support. Cronbach's alpha for macro-adaptive learning support was .68. Internal consistency for micro-adaptive learning support was good, but for macro-adaptive learning support it was only just acceptable.

The model assessing the dimensionality of the instrument shows acceptable fit values (Table 4; Gallagher and Brown 2013).

These results confirm that the rating instrument is reliable and valid for measuring the quality of micro- and macro-adaptive learning support.

3.2. Descriptives and group differences

Table 5 presents a summary of an ANOVA to test whether there were differences in the quality of learning support at t1 offered by members of group^{MICRO}, group^{MACRO}, and the control group. There were no significant differences between the groups. Standard correlations of all variables are provided in Appendix A.

Table 4. Goodness-of-fit indicators for the CFA models.

Measurement point	factors	df	χ2	*p*	χ2/df	CFI	RMSEA	SRMR
1	3	16	28.791	.025	1.80	.960	.080	.056
2	3	16	29.396	.021	1.84	.952	.079	.056

Table 5. Mean, standard deviation, and analysis of variance in quality of learning support at t1.

Measures	group^{MICRO}		group^{MACRO}		Control group			
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*(2, 129)	η^2
Subject-related micro-adaptive support	4.47	1.15	4.47	1.29	4.22	1.11	0.608 *ns*	.009
Social-emotional micro-adaptive support	6.11	0.93	6.15	1.03	6.22	0.95	0.147 *ns*	.002
Macro-adaptive learning support	9.40	2.24	9.67	2.44	9.47	2.31	0.160 *ns*	.002

Table 6. Sequential regression analysis predicting the quality of subject-related micro-adaptive learning support at t2.

Step and predictor variable	R^2	ΔR^2	*sr*	*B*	*SE B*	β
Step 1	.06*	.06*				
Program^{MICRO}			.24	.59	.21	.24**
Program^{MACRO}			.12	.30	.22	.12
Step 2	.24***	.18***				
Micro-adaptive support quality t1			.44	.39	.07	.42***
Step 3	.30***	.06*			.	
Country (0 = Germany; 1 = Switzerland)			-.16	-.35	.20	-.15
Professional training (1 = acad.; 0 = vocational)			.24	.65	.24	.25 **
Professional experience			-.03	-.003	.01	-.03

* $p < .05$. **$p < .01$. ***$p < .001$.

3.3. Impact of the programs on quality of learning support

Table 6 shows the results of a sequential regression analysis to predict the *quality of subject-related micro-adaptive learning support at t2*.

When the two dummy variables for the professional development programs were included, R^2 increased significantly ($F(2, 127) = 4.005$; $p < .05$; $R^2 = 0.059$). The micro-adaptive program has a significant influence on the quality of subject-related micro-adaptive learning support at t2 (β = .24**): Participants in group^{MICRO} provided a higher quality of subject-related micro-adaptive learning support than participants in group^{MACRO} or the control group.

Including the quality of subject-related micro-adaptive learning support at t1 in the second step resulted in a significant increase of R^2 ($F(3, 126) = 13.515$; $p < .001$; $R^2 = 0.243$). The effect of the quality assessment at t1 is highly significant (β = .42***): Teachers who provided a high quality of support at t1 also offered high quality adaptive learning support at t2.

Inserting the control variables in step 3 led to a significant increase of R^2, up to .30 ($F(6, 123) = 8.853$; $p < .001$; $R^2 = 0.302$), because of the influence of the professional training variable (β = .25**): Kindergarten teachers with an academic degree provided significantly higher quality subject-related micro-adaptive learning support than teachers with vocational training.

Overall, the model explains 30% of variance. According to Cohen (1969), this corresponds to a strong effect ($f^2 = 0.433$).

In a further model, the impact of the predictors on the dependent variable *quality of social-emotional micro-adaptive learning support at t2* was calculated (no table). When the variables of the professional development programs were included in the first step of the model, R^2 did not increase significantly ($F(2, 127) = 0.183$; $p = .833$; $R^2 = 0.003$).

Table 7 shows the results of the sequential regression analysis predicting the *quality of macro-adaptive learning support at t2*. Inserting the variables of the professional development programs in the first step led to a significant increase of R^2 ($F(2, 127) = 3.076$; $p < .05$; $R^2 = 0.046$). The macro-adaptive program has a significant influence on the quality of macro-adaptive learning support at t2 (β = .25**). Participants in group^{MACRO} provided a higher quality of macro-adaptive learning support at t2 compared to participants in group^{MICRO} and the control group.

Table 7. Sequential regression analysis predicting the quality of macro-adaptive learning support at t2.

Step and predictor variable	R^2	ΔR^2	*sr*	*B*	*SE B*	β
Step 1	.05*	.05*				
Program^{MICRO}			0.02	.07	.40	.02
Program^{MACRO}			0.25	1.18	.41	.25**
Step 2	.25***	.21***				
Macro-adaptive support quality t1			0.36	.35	.08	.36***
Step 3	.33***	.08**				
Country (0 = Germany; 1 = Switzerland)			0.14	.64	.40	.14
Professional training (1 = academic; 0 = vocational)			−0.01	-.07	.46	-.02
Professional experience			−0.26	-.05	.02	-.25**

* $p < .05$. ** $p < .01$. *** $p < .001$.

A significant increase of R^2 ($F(3, 126) = 14.145$; $p < .001$; $R^2 = 0.252$) was found when the quality of macro-adaptive learning support at t1 was included in the second step. The quality of macro-adaptive learning support at t1 (β = .36***) has a highly significant effect: Those teachers who already provided high quality macro-adaptive learning support at t1 also provided high quality macro-adaptive learning support at t2.

Inserting the control variables in step 3 led to a significant increase of R^2, up to .33 ($F(6, 123) = 10.026$; $p < .001$; $R^2 = 0.328$), because of the influence of the professional experience variable (β = -.25**): Kindergarten teachers with more professional experience provided significantly lower quality of macro-adaptive learning support than teachers with less professional experience.

The overall model explains 33% of variance. According to Cohen (1969), this corresponds to a strong effect ($f^2 = 0.488$).

4. Discussion and conclusion

This study investigated whether the quality of micro- and macro-adaptive mathematical learning support of 132 kindergarten teachers could be improved by targeted professional development programs.

As expected, the results of regression analyses revealed that the subject-related micro-adaptive program had a positive, if small, effect on the quality of subject-related micro-adaptive mathematical learning support, and the macro-adaptive program had a small positive effect on the quality of macro-adaptive support. Even though the effects were small, they were similar to the effects of the professional training on the quality of micro-adaptive learning support and professional experience on the quality of macro-adaptive support (Tables 6 and 7). The magnitudes of the effects are in line with the results of previous studies, which reported small to medium effects from professional development programs (Bruns, Eichen, and Gasteiger 2017; Fukkink and Lont 2007; Vick Whittaker et al. 2016; Werner et al. 2016). Small effects are quite common for professional development programs which do not include a long-term continuous development program that is integrated into the everyday professional life of the kindergarten teacher (Bruns, Eichen, and Gasteiger 2017). Although the study duration was 6 months, the program was not very intense and no continuous individual support was given. It is likely that a more intensive long-term program with the same content would have generated a larger effect (Urban et al. 2012).

The results also showed that the subject-related micro-adaptive program had no effect on the quality of macro-adaptive learning support and vice versa. These findings confirm the assumption that the two types of adaptive support are indeed different and have different competence requirements (Lindmeier 2011; Knievel, Lindmeier, and Heinze 2015). However, recent results from a study by Lindmeier et al. (2021) indicate that measuring these competences is challenging and the hypothesized link between these specific competences and the quality of subject-related micro-adaptive learning support is not as clear as expected. Therefore, further research is needed to examine the constructs of micro- and macro-adaptive learning support and the associated competences of kindergarten teachers.

No effect of the professional development program on social-emotional micro-adaptive learning support was found. This result was expected because the focus of the micro-adaptive program was instructional support.

Although the study did not explore research questions about the influence of the control variables, it provided some information worth considering. The results showed that participants with academic professional training provided a higher quality of subject related micro-adaptive learning support. Additionally, the pre-test data of this study showed that the quality of micro- and macro-adaptive learning support was predicted by country, but not by professional training (Meier-Wyder et al. 2022). The findings of other studies on the impact of training are inconclusive: The EPPE study (Sylva et al. 2004) indicated that a higher level of training has an impact on instructional quality in preschool institutions. However, a case study by Kucharz et al. (2014) found that this was not a very strong effect. Meanwhile Tournier (2017) reported that academic training had no impact on the level of cognitive activation during adaptive learning. The mixed results could be because measurement instruments and training curricula have differing objectives. For example, subject-related adaptive learning support is often only a small part of vocational education programs. It is important that future studies examine the relationship between professional training and achievement gains more closely.

The findings on the negative effect of professional experience on the quality of macro-adaptive learning support were unexpected. One possible explanation is that a greater focus on planning, preparation, and reflection has only recently found its way into the curricula of professional training programs for kindergarten teachers as the emphasis on academic learning in preschool institutions has increased (DeLuca, Pyle, and Lapointe-McEwan 2020; Pyle and DeLuca 2017). This might be especially true for Germany, where comprehensive mathematical curricula are not available in every state (Gasteiger, Brunner, and Chen 2021).

The study has limitations which might affect the interpretation of the results. The reliability scores for the quality of macro-adaptive learning support were only just acceptable. This could be because the number of ratings for each item was low. Also, the study could not evaluate whether the professional development program has a long-term effect on the quality of adaptive learning support.

The study shows that it is possible to bridge the gap between the significance attributed to high quality adaptive learning support and its observed quality in kindergartens by using targeted measures. It also highlights the importance of having programs specifically designed to improve micro- and macro-adaptive learning support. This outcome is

particularly relevant in an educational policy climate where academic progress in preschools is increasingly becoming a priority, especially in countries where academic learning in preschool (kindergarten) is not yet the norm.

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Declaration of interests

The authors confirm that this work is original and has not been published elsewhere nor is it currently under consideration for publication elsewhere.

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Appendix A. Standard correlations between adaptive learning support quality at t2, professional development programs, adaptive learning support quality at t1, and control variables

	n	1	2	3	4	5	6	7	8	9	10	11
1. Subject-related micro-adaptive support t2	132	—										
2. Social-emotional micro-adaptive support t2	132	.383**	—									
3. Macro-adaptive support quality t2	132	.361**	.315**	—								
4. Program^{MICRO}	132	.142	-.017	-.071	—							
5. Program^{MACRO}	132	.013	.054	.226**	-.475**	—						
6. Subject-related micro-adaptive support t1	132	.343**	.423**	.316**	.057	.006	—					
7. Social-emotional micro-adaptive support t1	132	.226**	.616**	.263**	-.040	-.004	.656**	—				
8. Macro-adaptive support quality t1	132	.247**	.331**	.460**	-.035	.048	.457**	.444**	—			
9. Country	132	-.039	.519**	.344**	.027	.010	.385**	.511**	.449**	—		
10. Professional training	132	.163	.253**	.224*	.031	-.068	.210*	.258**	.295**	.429**	—	
11. Professional experience	132	-.078	-.087	-.247**	-.096	.181*	-.029	-.052	-.123	-.103	-.432**	—

Note. *** $p < .001$. **$p < .01$.* $p < .05$.