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Preschool and primary school influences on the development of children's early numeracy skills between the ages of 3 and 7 years in Germany

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Few studies have investigated how preschool and primary school interact to influence children's cognitive development. The present investigation explores German children's numeracy skills between age 3 (1st year of preschool) and age 7 (1st year of primary school). We first identified the influence of preschool experience on development while controlling for child factors, family background, and the quality of the home learning environment (HLE). We then considered how the instructional quality of primary schools influences numeracy. We finally analysed how preschool and primary school interact. We sampled 547 children who attended 97 German preschools. Latent growth curve analyses identified child and family factors related to age 3 numeracy and development to age 7: gender, migration background, socioeconomic status (SES), mother education, HLE. The effects of preschool on numeracy development persist until age 7 with notable effects from process quality. Strengthened efforts are needed to ensure high quality preschool education in Germany.

Keywords: preschool quality; cognitive development; primary school quality; numeracy; longitudinal studies

Background and objectives

Large longitudinal studies have produced growing evidence of the potential benefits of preschool education for the cognitive development of children (see Gorey, 2001, for an overview). Whereas the evidence of short- and medium-term academic benefits of early education or preschool programs is compelling, findings on the persistence of beneficial preschool effects are mixed. It seems that the quality of the preschool setting attended is a crucial factor for the magnitude and the persistence of beneficial effects (e.g., Peisner-Feinberg et al., 2001; Sammons et al., 2008). Preschool quality covers multiple dimensions and relates to structural characteristics (e.g., class size, staff qualifications levels) as well as the professional beliefs and orientations of teachers with respect to learning processes and the process quality of the interactions between teachers and children. Process quality refers to global characteristics such as warm climate (Harms, Clifford, & Cryer, 1998) as well as domain-specific stimulation in educational areas (Kuger & Kluczniok, 2008; Sylva, Siraj-Blatchford,

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& Taggart, 2003). When children grow older, the learning experiences in primary school will further influence children's academic progress. Comparable to the construct of preschool quality, current frameworks of primary school quality differentiate between structural characteristics, teacher beliefs, and the quality of pedagogical processes (see European Child Care and Education [ECCE]-Study Group, 1999, for an empirical application). Theories of instructional quality in school classrooms underline the impact of three dimensions of instructional quality: classroom management, supportive climate, and cognitive activation (e.g., Baumert et al., 2010; Klieme, Pauli, & Reusser, 2009). Some studies have shown that high instructional quality may have positive effects on children's cognitive development (e.g., Pianta, Belsky, Vandergrift, Houts, & Morrison, 2008; Rossbach, 2002). As most children attend preschool as well as primary school, it is of special interest to understand how these educational settings interact. It is possible that a high-quality preschool experience gives children a better start to primary school and that these early benefits are maintained over years. Furthermore, a high-quality preschool experience might not only give children a better start to school but also prepare them in a way that they show better progress as they move through primary school. On the other hand, beneficial preschool effects might also vanish very quickly; and once children attend primary school, the instructional quality and effectiveness of the primary school might compensate for any preschool effects. Empirical evidence on interactive effects of both educational settings is rare. At this time, it is not possible to draw a final conclusion (e.g., Magnuson, Ruhm, & Waldfogel, 2007; National Institute of Child Health & Human Development of Early Child Care Research Network [NICHD ECCRN], 2006; Sammons et al., 2008; Tietze, Rossbach, & Grenner, 2005).

Certainly, schooling factors are not the only factors with potential influence on children's development and educational careers. It is well known that a number of child characteristics and family factors (e.g., parental education levels, socio-economic status) may have a significant impact (e.g., Cox, 2000; NICHD ECCRN, 2002; Pianta & Hamre, 2009). Already when children enter primary school, their cognitive skills vary markedly according to their gender, ethnicity, or the social background of the family (e.g., Dubowy, Ebert, von Maurice, & Weinert, 2008; Strand, 1995, 1997, 1999; Tymms, Merrell, & Henderson, 1997). Additionally, the quality of the home learning environment (HLE) may influence children's development (e.g., Hart & Risley, 1995; Melhuish et al., 2008; Snow & Van Hemel, 2008). It is related to the availability of educational resources such as books or educational games and the nature of parenting activities (e.g., reading to a child, playing with numbers, taking the child to a library). Thus, when investigating potential effects of preschool and primary school education, potential effects of child factors, family factors, and the quality of the HLE need to be also considered.

The longitudinal project BiKS in Germany

Empirical evidence on effects of preschool education is rare in Germany. The longitudinal project BiKS (Bildungsprozesse, Kompetenzentwicklung und Selektionsentscheidungen im Vor- und Grundschulalter [Educational processes, competence development, and selection decisions at pre- and primary school age]) was set up to shed light on how learning environments at home, at preschool, and at primary school differentially influence children's development (Schmidt, Smidt, & Schmitt, 2009; von Maurice et al., 2007). The substudy BiKS 3–10 follows the acquisition of competencies of 547 children in Germany who attended 97 preschool settings in two federal states (Bavaria and Hesse) since 2005.

Based on the BiKS dataset, we recently examined the development of early numeracy skills and growth in this cognitive domain between the ages of 3 and 5 years while children move through preschool (Anders et al., 2012). With respect to the impact of child and family background factors, the findings revealed that gender, parental native language status, parental education, and socioeconomic status (SES) are related to initial achievement levels as well as to further growth. Further, a strong effect of the quality of the learning environment at home (HLE) on initial numeracy skills could be established. A number of structural characteristics of the preschool setting (e.g., spatial size of the setting, average age of the class) are also associated with initial achievement. But when we look at developmental progress, the process quality of the preschool settings in terms of fostering academic skills as measured by Early Childhood Rating Scale Extensions (ECERS-E; Sylva et al., 2003) makes the difference. Stated precisely, it is the quality of stimulation in mathematics that has the strongest impact on growth between the ages of 3 and 5 years.

The present study

In the current study, we explore the development of early numeracy skills of children between the ages of 3 and 7 years in Germany.[1] This age range covers 3 years of preschool and the 1st year of primary school. We focus on schooling effects and investigate how preschool and primary school influences interact in shaping young children's acquisition of numeracy. In particular, this study addresses three research questions. First, it seeks to identify the influence of preschool experience on developmental progress between age 3 and age 7 while controlling for relevant child factors, family background, and the early years HLE. We are especially interested if the beneficial effects of different indicators of process quality of preschool settings persist until the end of the 1st year of primary school. Second, we investigate how the instructional quality of the primary school further influences the development of numeracy skills when children have moved from preschool to primary school. Third, we analyse how preschool and primary school influences interact.

Method

Procedure and sample

The present investigation analyses the development of early numeracy skills over four measurement points (average age 3, 4, 5, and 7 years). The first three measurement points took place while children were in preschool, the last measurement point took place during the last 6 weeks of the 1st year of primary school. The average number of children assessed per preschool class was 5.5.[2] Most of the 547 BiKS children moved from preschool to primary school in September 2008. At this time, the sample includes 435 children; 142 primary school classes participate in the study (Schmidt et al., 2009). Looking at the background of the children in the initial sample, we find that 19.6% of the children have one or two parents with a mother tongue other than German. With respect to mother's education, we find 34.0% with a qualification for university entrance.

Parents gave information about their family structure, occupational and educational background, as well as parent–child activities and routines in interviews and questionnaires. Further information was obtained through observations at home, which were also conducted annually. Structural characteristics and measures of the process quality in the preschool settings were obtained through interviews with the heads of the preschools, staff questionnaires, and observations. Staff interviews were carried out twice a year, observations in the settings were repeated annually. Since spring 2009, different aspects of general and subject-specific aspects of instructional quality at the primary schools were obtained by observations.

Measures

Outcome measure

Early numeracy skills over the investigated period were assessed by the subscale "arithmetics" of the German version of the Kaufman Assessment Battery for Children (K-ABC, Melchers & Preuss, 2003). This scale measures children's skills in counting, identifying numbers, knowledge of shapes, and understanding of early mathematical concepts. It is internationally well known and established. In contrast to other instruments, it can be applied over a wide age range.

The test is organized into sets of three to five items of increasing difficulty. Children score one point for each item answered correctly. Testing is stopped when a child answers all items in a subset incorrectly. Thus, potential practice effects are reduced when applying the test. The test items are embedded in a story about a family visiting a zoo, which is presented verbally with accompanying pictures. In Sets 1 and 2, the child has to count objects, identify numerals up to 10, and identify two-dimensional shapes. In Sets 3 and 4, the child has to solve various numerical problems in the number range up to 10: comparing quantities of pictured objects, understanding numbers as symbols, and solving verbally presented subtraction problems supported by pictures. In Sets 4 and 5, the child has to read numbers greater than 10, solve verbally presented arithmetic problems that cross the "10" boundary, and do simple multiplication and division tasks. From Set 6, children's skills in dealing with numbers higher than 100 and with scale units are assessed, as well as their ability to solve more complex multiplication and division tasks embedded in the story. We used raw scores so that change over time could be better documented.

Predictors

Child and family background factors. Gender, age in months, parental native language status (German/other), highest socioeconomic status of the family, maternal education, and age at entry to the preschool setting were used as child and family background control variables. As measure of the socioeconomic status of the family, the International Socio-economic Index of Occupational Status (ISEI, Ganzeboom, De Graaf, & Treiman, 1992) was derived.

Early years home learning environment (HLE). The assessment of characteristics that provide an indication of the early years HLE in promoting (pre)reading literacy and numeracy skills is based on (a) self-constructed questionnaires and interviews, (b) the adapted version of the Home Observation for Measurement of the Environment (HOME; Caldwell & Bradley, 1984), and (c) a semi-standardized book reading task between parent and child called the Family Rating Scale (Kuger, Pflieger, & Rossbach, 2005). One scale measure to assess the quality of the early years HLE was developed considering information from all three data sources. The scale contains 20 items which refer to activities as well as to material. Example items are stimulation to learn the alphabet, frequency of shared book reading, counting activities, and stimulation to learn spatial relationships. The internal consistency (Cronbach's alpha) at the three measurements is 0.74, 0.77, and 0.77, respectively. For the following analyses, the scale was standardized to a range of 0 to 1, and one indicator representing overall quality was derived by taking the means of the composite over the three measurements.

Preschool measures

Structural (quality) factors. Structural (quality) factors included the proportion of children with a parental native language different from German in the class, class size, child–staff ratio, m^2 per child, and the average age of children in the class. The federal state was treated as a control.

Process quality. The quality of preschool measure is based on observations of each preschool setting using environment ratings (German versions of ECERS-R and ECERS-E). This study focused on ECERS-E (Sylva et al., 2003), which is a measure of process quality considering four educational aspects: the quality of learning environments for verbal, mathematics, and science literacy and taking care of diversity and individual learning needs. The overall score of ECERS-E as well as the subscale "mathematics" were used in the present analyses. These were the indicators which had shown to have an effect on the development of numeracy skills between age 3 and age 5 (Anders et al., 2012). Although some preschool characteristics are naturally subject to change (e.g., class composition), the correlations between the assessments are moderate. For all preschool measures, average scores of the annual assessments were used in the following analyses to keep the complexity of the following statistical models at a reasonable level.

Primary school measures

Instructional quality in mathematics. The measurement of quality of instruction in mathematics is based on classroom observations assuming three dimensions of instructional quality (Klieme et al., 2009): supportive climate, classroom management, and cognitive activation. In this study, we focus on cognitive activation in mathematics lessons. It was covered by five items (Steinweg, 2009). Example items are: "positive culture of handling mistakes" and "transparency of lesson's goal". The items were aggregated to a scale measure (Cronbach's alpha = .82).

Statistical analyses

To examine the influences on the development of numeracy skills over time, two strings of analyses were conducted. In the first string, we analysed the development of numeracy skills between age 3 and age 7. The main focus of the first set of analyses was to investigate if effects of preschool experience continue until age 7. Latent linear growth curve (LLGC) models were fitted to the data with four repeated measurements (numeracy skills at first, second, third, and fourth assessment). A stepwise procedure was carried out. First, a null model with an intercept and a linear slope was specified, only considering age at assessment as time-varying predictor of numeracy skills and growth. Then child, individual background factors, and the quality of the HLE were tested as potential influencing factors for initial attainment and growth (LLGC – Model 1). Model 1 served as the control model. In a third step, structural (quality) characteristics of the preschools were additionally included in the models (LLGC – Model 2). Fourth, indicators of preschool quality were tested individually while controlling for the other variables (LLGC – Model 3a, Model 3b). Finally, we tested whether effects of preschool quality remain stable when including quality of instruction at primary school in the models (LLGC – Model 4a, Model 4b). Model fit was evaluated by root mean square error approximation (RMSEA) and comparative fit index (CFI) (see Hu & Bentler, 1999). The data have a nested structure, with children being nested in preschool classes (age 3 to age 5) or primary school classes (age 7), respectively. Although the numbers of children per preschool or primary school class were low, ignoring the clustering may lead to unreliable standard errors. We used standard errors adjusted for the multilevel structure of the data. As the preschool classes are the main source of clustering between age 3 and age 7, we decided to take account of the clustering by preschool classes.[3] The sample size for the first string of analyses was $n = 532$ children with at least one valid outcome measure and predictor. The strategy of analyses for this string of analyses is illustrated in Figure 1.

A second string of analyses was conducted to explore the influence of the instructional quality in mathematics at the primary school attended in more detail. In this string, we focused on the development between age 5 (last year of preschool) and age 7 (first year of primary school) using multivariate value-added regression analyses. The outcome was achievement in numeracy at age 7. First, influences of

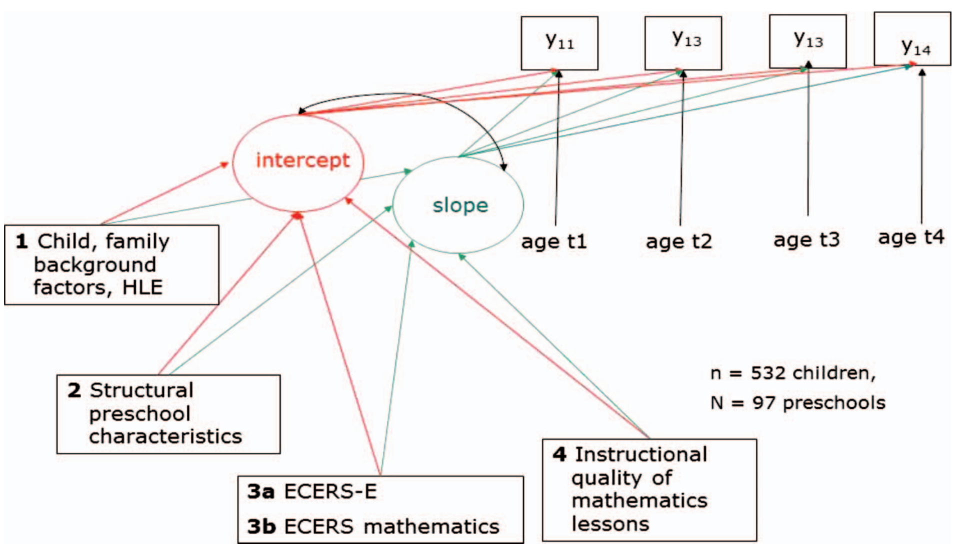

Figure 1. Latent linear growth curve models: stepwise procedure.

preschool quality on achievement were investigated controlling for attainment at age 5 and all other child, background, home learning, and preschool characteristics (Regression model 1a: including ECERS-mathematics, Regression model 1b: including ECERS-E). Second, instructional quality of the primary school was added, controlling for all predictors included in Model 1 (Regression model 2a: including ECERS-mathematics, Regression model 2b: including ECERS-E). In the next step, interaction terms (process quality of preschool x instructional quality of primary school) were specified and included in the model. As the primary school classes were the main source of clustering for the outcome in this string of analyses, standard errors accounting for the clustering by primary school classes were estimated. The sample size for the second string of analyses was $n = 396$ children with at least one valid outcome measure and predictor. The strategy for this string of analyses is illustrated in Figure 2.

All analyses were carried out using MPlus version 5.2 (Muthén & Muthén, 2008). To deal with missing data, we chose the full information maximum likelihood (FIML) approach (e.g., Arbuckle, 1996) that is implemented in MPlus and uses valid information of all observations for model estimation. To account for possible selection bias (e.g., NICHD ECCRN & Duncan, 2003), we included child and family background indicators which might be correlated with the outcome as well as with indicators of the quality of learning environments. All continuous variables were z standardized before included in the multivariate analyses or before building interaction terms.

Results

Descriptives

Table 1 shows descriptive statistics for the outcome and predictors. The descriptives shown for the quality of the HLE and preschool characteristics represent mean scores of all available assessments while the children moved through preschool.[4]

The results illustrate the average growth of achievement in arithmetic over the duration of the study. There were no indications of any floor or ceiling effects over the investigated period. Looking at the quality of the HLE, we observe substantial variance between families. With regard to the preschool characteristics, the observed

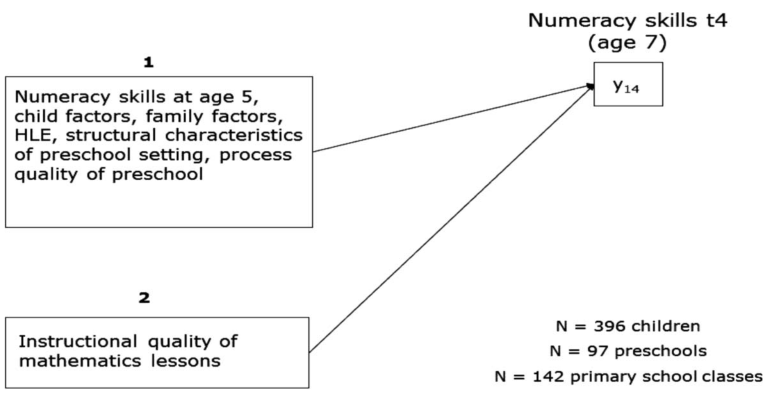

Figure 2. Multivariate value added regression analyses: stepwise procedure.

Table 1. Descriptives.

Child sample ($N = 532$)	Mean	*SD*	Min	Max
Outcome				
Arithmetics score t1	4.96	3.37	0	14
Arithmetics score t2	10.40	3.91	0	20
Arithmetics score t3	15.08	3.74	2	27
Arithmetics score t4	22.51	3.10	5	32
Home learning environment (HLE)	0.47	0.12	0.03	0.77
Preschool sample ($N = 97$)				
Structural characteristics				
Class size	23.82	3.69	11.00	36.33
Average age of all children in the class	5.05	0.24	4.31	5.70
Child-to-staff ratio	11.35	2.50	5.67	19.00
Proportion of children whose parents had a native language other than German	0.24	0.25	0.00	0.90
M^2 per child	3.46	2.25	1.47	16.00
Indicators of process quality				
ECERS-E	2.98	0.53	1.76	4.07
ECERS-mathematics	2.63	0.79	1.44	4.67
Primary school class sample ($N = 142$)				
Level of cognitive activation in mathematics	3.21	1.18	1.20	6.00

Note: For achievement in arithmetics, the average raw scores (non-standardized) are shown.

process quality is of special interest. We see that the quality in terms of promoting domain-specific skills and abilities is low or medium in most of the preschools observed. The mean of instructional quality in mathematics is 3.21, and we also find substantial variance between primary school classrooms.

How are child characteristics, family factors, and early years home learning environment related with the development of numeracy skills between age 3 and age 7? (LLGC – Model 1)

The impact of the control variables on initial numeracy skills and their development over years was explored with growth models. The null model confirmed the linear growth of numeracy skills over the years as well as that the age of the child is a significant predictor at all measurement points (Year 1: b = 0.30***, Year 2: b = 0.31***, Year 3: b = 0.27***, Year 4: b = 0.26***, unstandardized coefficients). In Model 1, explanatory individual child, family background factors and the quality of the learning environment at home (HLE) were additionally included as predictors (Table 2). The results show that gender, parental native language status, and the socioeconomic status of the family have a significant influence on initial achievement levels (intercept) as well as on further growth (slope). Mother's educational level and the quality of the early years HLE are associated with the intercept but not the slope. Girls start better (b = −0.29, $p < 0.01$), but boys catch up and even show slightly better achievement at the end of the 1st year of primary school (b = 0.94, $p < 0.001$). Children whose parents have a native language different from German show lower achievement at the first assessment (one parent: b = −0.66, $p < 0.001$, both parents: b = −0.90, $p < 0.001$), but compared to their peers with native German parents they show relatively stronger growth over the years (one parent: b = 0.80, $p < 0.05$, both

Table 2. Results of latent growth curve analyses to predict the development of numeracy skills between the first and fourth assessment.

	LLGC Model 1			
	Intercept		*Slope*	
Predictors	*B*	*SE (B)*	*B*	*SE (B)*
Child and family background factors				
Age of child at entry to the preschool setting	−0.11#	0.06	0.16	0.12
Gender (0 = female, 1 = male)	−0.29**	0.09	0.94***	0.24
Parental native language status				
Reference category: none				
One parent	−0.66***	0.18	0.80*	0.36
Both parents	−0.90***	0.20	1.96***	0.48
Mother's education				
Reference category: no degree or a degree at vocational level				
General certificate of secondary education	0.18	0.12	0.12	0.27
Qualification for university entrance in Germany	0.25	0.15	0.20	0.34
Any other degree	0.67*	0.22	−0.64	0.61
Highest socioeconomic status of the family	0.12*	0.06	0.30*	0.13
Home learning environment (HLE)	0.23***	0.05	0.08	0.13
Slope with Intercept	B = −0.09		*SE* = 0.25	
R^2	0.29***		0.63**	
CFI/RMSEA	0.91/0.07			

Notes: In all models, age at assessment was included as time-varying predictor, although not shown in the table. Coefficients are standardized using the variances of the continuous latent variables (Std-standardization). #$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

parents: b = 1.96, $p < 0.001$). With respect to the influence of the socioeconomic status of the family (HISEI), we find that children with higher socioeconomic status have higher numeracy skills already at the first assessment (b = 0.12, $p < 0.05$) and that the achievement gap widens over the following years (b = 0.30, $p < 0.01$). Early years HLE has a strong effect on numeracy skills at age 3 (intercept, b = 0.23, $p < 0.01$), but there is no further significant effect of HLE on the slope. The fit of Model 1 is moderate (CFI = 0.91, RMSEA = 0.07).

How are characteristics of the preschool settings related with the development of numeracy skills between age 3 and age 7? (LLGC: Models 2, 3a, 3b, 4a, 4b)

In the next step, the influence of preschool indicators was examined. LLGC model 2 (Table 3) includes structural characteristics of preschool settings as potential predictors while controlling for all factors tested in Model 1. The results indicate that the average age of children in the class (b = 0.11, $p < 0.05$) is positively related to initial numeracy skills, whereas the number of children with non-German native parents in the class has a negative influence (b = −0.15, $p < 0.05$). Class size is also negatively associated with initial numeracy skills (b = −0.13, $p < 0.01$), but children who are part of larger classes tend to catch up over years (b = 0.18, $p < 0.10$). Also,

Table 3. Results of latent growth curve analyses to predict the development of numeracy skills between the first and fourth assessment.

	LLGC Model 2				*LLGC Model 3a*				*LLGC Model 3b*			
	Intercept		*Slope*		*Intercept*		*Slope*		*Intercept*		*Slope*	
Predictors	*B*	*SE (B)*	*B*	*SE (B)*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Structural preschool characteristics												
Class size	−0.13**	0.04	0.18#	0.10	−0.13**	0.04	0.19*	0.09	−0.13**	0.04	0.18*	0.09
Average age of children in the class	0.11*	0.05	−0.16	0.11	0.11*	0.05	−0.18	0.11	0.11*	0.05	−0.17	0.11
Child-to-staff ratio	−0.01	0.06	0.07	0.11	−0.01	0.06	0.06	0.11	−0.01	0.06	0.05	0.11
Proportion of children whose parents had a native language other than German	−0.15*	0.07	0.18	0.15	−0.14*	0.07	0.20	0.15	−0.14*	0.07	0.17	0.15
M^2 per child	0.13**	0.04	−0.18#	0.10	0.13**	0.04	−0.20*	0.09	0.13**	0.04	−0.18#	0.10
Federal state	0.43**	0.13	−0.67*	0.27	0.41**	0.13	−0.82*	0.28	0.41**	0.13	−0.85**	0.29
Process quality												
ECERS-E					0.04	0.06	0.19#	0.11				
ECERS-Mathematics									0.03	0.05	0.20*	0.10
Slope with Intercept	B = 0.06		*SE* = 0.33		B = 0.04		*SE* = 0.33		B = 0.04		*SE* = 0.34	
R^2	0.35***		0.73**		0.35***		0.75**		0.35***		0.76**	
CFI/RMSEA	0.89/0.07				0.90/0.06				0.90/0.07			

Notes: The models controlled for all predictors of Model 1 as well as HLE literacy and HLE numeracy although not shown in the table. Coefficients are standardized using the variances of the continuous latent variables (Std-standardization). $^{\#}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

the spatial size is positively related to initial achievement (b = 0.13, $p < 0.01$). We observe a significant effect for the federal state indicating that children from Hesse compared to children from Bavaria have lower initial skills (b = 0.43, $p < 0.01$) but show better progress over years (b = −0.67, $p < 0.05$). The amount of explained variance of Model 2 is 35% (intercept) and 73% (slope), respectively, model fit is moderate (CFI = 0.89, RMSEA = 0.06).

To investigate if effects of preschool quality persist until the end of the 1st year of primary school (age 7), indicators of the process quality of the preschool were added in LLGC models 3a and 3b. None of the indicators has a significant influence on initial achievement levels (see Table 3). The overall ECERS-E score just failed to reach statistical significance in its impact on growth between age 3 and age 7 (b = 0.19, $p = 0.08$), but ECERS-mathematics has a significant influence on growth (b = 0.20, $p < 0.05$). Model fit of Models 3a and 3b is satisfying; the models explain 35% of variance of the intercept, amounts of explained variance of the slope are 75% and 76%, respectively.

Children who went to higher quality preschool settings might also have moved to higher quality primary schools. One might argue that the persisting effect of preschools' process quality on the development of numeracy skills is reflecting a positive effect of primary schools' instructional quality in mathematics rather than showing a persisting effect of preschool quality. In our sample, we find only low but negative correlations between preschools' process quality and primary schools' instructional quality in mathematics (ECERS-E: $r = -0.05$, ECERS-mathematics: $r = -0.03$). Also, the beneficial effects of ECERS-mathematics (b = 0.21, $p < 0.05$) and ECERS-E (b = 0.21, $p < 0.10$) on growth remain stable in the models (4a, 4b) when controlling for the instructional quality in mathematics at the primary school attended (b = 0.08, $p > 0.05$). The strengths of the effects of the other predictors included in Models 4a and 4b also remain stable when primary schools' instructional quality is added. Therefore, Models 4a and 4b are not shown in Table 1.

How do the qualities of pre- and primary school interact in their influence on numeracy skills between age 5 and age 7? (Regression models 1a, 1b, 2a, 2b)

We further focused on the development between age 5 and age 7, when children move from preschool to primary school and have their first primary school experiences. In multivariate value-added regression analyses, numeracy skills at age 7 were treated as an outcome. In the first step, the influences of preschools' process quality on achievement were investigated controlling for achievement at age 5 and all other child, background, home learning, and preschool characteristics. Second, we included the quality of mathematics instruction in the models. Table 4 shows the results of the models including the subscale "mathematics" of ECERS-E (Regression models 1a, 2a). It should be noted that the coefficients may not be compared directly with the coefficients obtained in the latent growth models. The results demonstrate that – as expected – numeracy skills at age 5 are highly predictive for numeracy skills at age 7 (b = 0.48, $p < 0.001$). We further see that the socioeconomic status is also related with progress between age 5 and age 7 (b = 0.13, $p < 0.05$), whereas parental native language status and mother's educational level are not. Interestingly, the quality of early years HLE shows an effect for development between age 5 and age 7 (b = 0.09, $p < 0.05$). But while observing this, one has to consider that testing the effect of HLE in the latent growth model is more conservative than testing it in

Table 4. Results of regression analyses to predict the development of numeracy skills between the third (age 5) and fourth assessment (age 7).

	Regression Model 1a		*Regression Model 2a*	
Predictors	*B*	*SE (B)*	*B*	*SE (B)*
Child and family background factors				
Age at fourth assessment	0.15***	0.04	0.15***	0.04
Numeracy skills at third assessment (age 5)	0.48***	0.05	0.48***	0.04
Age of child at entry to the preschool setting	−0.05	0.05	−0.05	0.05
Gender (0 = female, 1 = male)	0.06#	0.03	0.06#	0.03
Parental native language status				
Reference category: none				
One parent	0.02	0.04	0.02	0.04
Both parents	0.01	0.04	0.01	0.04
Mother's education				
Reference category: no degree or a degree at vocational level				
General certificate of secondary education	0.01	0.06	0.00	0.06
Qualification for university entrance in Germany	0.07	0.08	0.07	0.08
Any other degree	0.02	0.06	0.02	0.06
Highest socioeconomic status of the family	0.13**	0.05	0.13**	0.05
Home learning environment (HLE)	0.09*	0.04	0.09*	0.04
Structural preschool characteristics				
Class size	0.11*	0.03	0.11*	0.04
Average age of children in the class	0.01	0.03	0.01	0.04
Child-to-staff ratio	−0.04	0.03	−0.04	0.03
Proportion of children whose parents had a native language other than German	0.01	0.04	0.01	0.04
M^2 per child	−0.02	0.04	−0.02	0.04
Federal state	−0.15**	0.05	−0.15**	0.05
Process quality preschool				
ECERS-Mathematics	0.07*	0.04	0.08*	0.04
Process quality primary school				
Level of cognitive activation in mathematics			0.03	0.05
R^2	0.41***		0.41***	

Notes: Standardized coefficients are shown. $^{\#}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

value-added regression analyses considering two measurement points only. With regard to preschool characteristics, the findings indicate that children who attended larger preschool classes (b = 0.11, $p < 0.01$) and children from Hesse (b = −0.15) show better progress. The process quality of the preschool setting in fostering mathematical skills (ECERS-mathematics: b = 0.07, $p < 0.05$) is also predictive for development. This result underlines that children not only start with better skills but also move forward faster in primary school when they attended a high quality preschool centre before. The results for Model 2a show that the quality of instruction in mathematics in the primary school class attended fails to show significant influence on progress (b = 0.03, $p > 0.05$), but the effect of preschool quality remains stable (b = 0.08, $p < 0.05$).

The same set of analyses was run using the ECERS-E total score as indicator of the process quality of the preschool (Regression models 2a, 2b). The pattern of results is similar to the pattern obtained for ECERS-mathematics and therefore not shown in a table. While the total score of ECERS-E failed to reach statistical significance for growth over the whole period between age 3 and age 7, we now find a significant effect for progress between age 5 and age 7 (b = 0.09, $p < 0.05$). Again, primary school's quality of instruction in mathematics has no additional predictive value (b = 0.03, $p > 0.05$), and the process quality of the preschool does not loose its predictive power (b = 0.09, $p < 0.05$).

Finally, we tested whether we could establish interactive effects of the qualities of the learning environments in both settings. Both interaction terms *(ECERS – mathematics x quality of instruction in mathematics, ECERS-E x quality of instruction mathematics)* did not have any significant influence on numeracy skills at age 7 when controlling for attainment at age 5 and all other background, family, home learning, and preschool characteristics (b = *ECERS – mathematics x quality of instruction in mathematics:* b = −0.03, $p > 0.05$; *ECERS-E x quality of instruction mathematics*: b = −0.06, $p > 0.05$). Taken together, results indicate that the instructional quality of mathematics lessons in primary schools needs more time to take a significant effect than just 1 year. At this time, it is still the prior preschool experience having greater influence on progress in numeracy.

Discussion

The presented study investigated the development of numeracy skills between age 3 and 7 and provided insight into the influences of preschool characteristics and primary school quality controlling for child, family background, and home learning factors. The results show, on the one hand, that achievement differences due to social background, family factors, and the quality of the home learning environment emerge very early in the lives of young children. This is in line with findings of other studies (e.g., Anders et al., 2011; ECCE Study Group, 1999; NICHD ECCRN, 2002; Sammons et al., 2004). But, on the other hand, we see that school experiences can make a difference. Looking at the effect of preschool characteristics over the whole age range (age 3 to age 7), we find that structural characteristics of the class and the setting are associated with initial achievement levels of children. Classes of smaller size, classes of higher average age, and classes with fewer children whose parents have a different mother tongue than German show better initial numeracy skills. Furthermore, the spatial size of the preschool setting is also associated with better achievement. When developmental growth over the whole age range is examined, none of these indicators has a significant influence. All the indicators that are related to initial numeracy skills are understood as quality indicators or are known to be correlated with process quality in German preschool classes (Kuger & Kluczniok, 2008). Thus, the observed associations are reflecting the current understanding of producing quality in preschool settings. However, it is striking that they do not explain significant variance in children's developmental growth over time. As most of the children usually have already spent a couple of months in the setting when they are tested the first time, this might point to the fact that achievement differences due to structural quality differences show up already shortly after the children have entered preschool. Selection bias might be an alternative explanation, and although we controlled for child and family background factors, we cannot rule out that possibility completely (NICHD ECCRN & Duncan, 2002). The results are in line with findings of Strand (1997, 1999), who reports significant preschool effects on initial cognitive achievements at age 4, but not on progress between age 4 and 7. His analyses are based on large samples of English children. When we turn to the effect of preschools' process quality, the study documented clearly that effects of preschools' process quality in fostering academic skills, especially mathematics, persist until the end of the first grade of primary school (age 7), regardless of the level of cognitive activation in the mathematics lessons at the primary school attended. Our results underpin the argument that beneficial effects of high quality preschool experience may persist for a while, regardless of the primary school context (e.g., Gorey, 2001, Sammons et al., 2008). The number of preschool centres that provide high quality in terms of fostering children's academic skills is relatively small in Germany (Kuger & Kluczniok, 2008). Due to this fact, the variance of preschool quality in the sample is naturally reduced, and it is very likely that the impact of preschool quality on children's development is even underestimated (see Anders et al., 2012, for a detailed discussion of the association between variance and predictive power).

Focusing on the further development when children have moved to primary school (age 5 to age 7), findings show that the quality of HLE while children were in preschool has an effect on the development of numeracy skills. The quality of the early years HLE is most likely to be correlated with parental support during the first grade of primary school. Furthermore, studies conducted in other countries were also able to establish long-lasting effects of the quality of the early years HLE (e.g., Melhuish, 2010). With regard to effects of preschool characteristics, we find that children who were cared for in larger classes make better progress in the 1st year of primary school. One possible explanation is that children who attended relatively larger classes in preschool are already used to the larger group contexts they have to be accustomed to in primary school. When we look at the interactive effects of preschool quality and primary school quality, results point to interesting conclusions. First, preschool quality in terms of fostering children's academic skills does not only give children a better start to school but also seems to give them a boost for better progress in their numeracy skills. Second, the level of cognitive activation of mathematics instruction has no significant additional effect on progress and in the 1st year of primary school. It cannot compensate for the effects of low-quality preschool experience. But one also has to take into account that the outcome measure is not based on the curriculum in mathematics first grade, though measuring an important aspect of mathematical competence. Other studies have also shown that the relationship between classroom context and cognitive progress seems to be complex (e.g., Curby, Rimm-Kaufman, & Ponitz, 2009; Pianta et al., 2008), and it might be necessary to consider additional factors like emotional support to show differential effects. We also assume that effects of instructional quality will increase the longer the children are exposed to it. They might be evident when children move further through primary school, although we did not find them in this study when children have spent only a couple of months in primary school.

Implications, limitations, and future research

The study has provided evidence for the potential of *high-quality* early education programs to foster numeracy skills in Germany. Recent policy changes in Germany seem to point in the right direction, and the study underlines that it is important to invest in high quality preschool settings.

But the possible conclusions of BiKS 3–10 are limited by the fact that data collection started at age 3 and not earlier (at birth). Furthermore, no control group without preschool experience is available. We are aware that due to these facts the design does not allow for any conclusions regarding the effect of preschool experience compared to no preschool experience, and it will also not be possible to rule out the possibility of selection bias completely. While this paper focused on the development of numeracy skills, the findings of Ebert and colleagues on vocabulary development in this special issue highlight that it is not possible to generalize to other cognitive domains and that differential effects for certain groups of children (e.g., children with migration background) deserve more attention. In addition, we will investigate possible influencing factors at primary school age in more detail.

Notes

1. The study is conducted within two subprojects (grant to S. Weinert and H.-G. Rossbach) of the larger interdisciplinary research group BiKS, funded by the German Research Foundation. We would like to thank all participating children, their parents, and their preschool teachers, as well as all students engaged in data collection for their most active cooperation.
2. Please note that this number is not equivalent to the class size as preschool classes usually were mixed-age groups, and therefore primary school enrolment was not due in 2008 (inclusion criterion) for all the children of one class.
3. Please note that the potential effects of clustering in all these analyses are generally low. The pattern of results remains the same if standard errors adjusted for the clustering by preschool classes or primary school classes are used. The pattern of results remains also stable if standard errors not adjusted for the multilevel structure are estimated.
4. The shown descriptives for preschool measures are slightly different to those reported in the paper of Anders and colleagues (2012). This is due to the fact that for the present analyses one further measurement point of preschool indicators could be included in the analyses.

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