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The Relationship of Mathematical Competence and Mathematics Anxiety: An Application of Latent State-Trait Theory

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Abstract

In educational contexts, it is assumed that mathematical competence can be viewed as a trait. However, studies have yet to examine whether mathematical competence is actually a stable personality characteristic or rather depends on situational factors. Thus, construct validity has not yet been confirmed in this respect. The present study closes this research gap with respect to prospective pre-school teachers when measured across measurement occasions with similar situational characteristics. This study also examines the idea that math anxiety is a relevant negative predictor of mathematical competence. Both research objectives were examined using latent state-trait theory (LST) modeling, which allows for the investigation of occasion-independent and occasion-specific variability over time. The competence and anxiety of n=354 prospective pre-school teachers were assessed twice across a period of three weeks. Results indicated no occasion-specific effects and moderate negative relations between math anxiety and all mathematical domains. The utility of LST modeling for construct validation and the investigation of complex relationships is discussed.

Keywords: Mathematical Competence, Math Anxiety, Latent State-Trait Theory, Pre-school Teachers

Theoretical Background

Early Education in the Field of Mathematics and the Mathematical Competence of Prospective Pre-school Teachers

In recent years, several studies have shown that pre-school children are able to develop notable mathematical competence and that this competence predicts their later achievement in mathematics at school (e.g., Krajewski & Schneider, 2009). However, this development strongly depends on the quality of the support provided by pre-school teachers (Reynolds, 1995). Therefore, pre-school teachers should be competent at fostering children's mathematical development (Burchinal et al., 2008; Klibanoff, Levine, Huttenlocher, Vasilyeva & Hedges, 2006).

According to Shulman's theoretical work (1986), teachers' competence can be divided into several content- and pedagogy-related facets. Studies that have empirically tested this model have supported its validity with respect to prospective primary school teachers (Blömeke, Kaiser & Lehmann, 2010). According to these studies, mathematical competence as one content-related model facet consists of several domains (number and operations; quantity and relation; geometry; data, combinatorics, and chance) and processes (problem solving; modeling; communicating; representing; reasoning; patterns and structuring). Given the frequent use of this model in standards, it can be seen as internationally valid (e.g., Common Core State Standards Initiative, 2014) and was also applied by the German Standing Conference of the Ministries of Education (KMK, 2004). It was also validated in analyses of pre-school teacher education curricula and standards for early education in all federal states in Germany (Jenßen et al., 2013) as part of our KomMa study. [1]

In Germany, up to 95% of pre-school teachers are trained at early-education vocational schools, which accept students with a middle-school or high-school degree depending on the state. A small proportion of these teachers are trained at universities for applied sciences (Metzinger, 2006). The regular duration of prospective pre-school teachers' training in Germany averages three years. A systematic analysis of all pre-school teacher education curricula within *KomMa* showed that mathematics could not be considered a regular subject during the training (Jenßen et al., 2013).

Math Anxiety

In the field of mathematical competence, math anxiety has been discussed as a moderately negative predictor of varying relevance for achievement in math (Ma, 1999). Math anxiety is defined as "feelings of tension and anxiety that interfere with the manipulation of mathematical problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972, p. 551), and it consists of cognitive and affective components (Ashcraft, 2002).

Studies have revealed that math anxiety is more common among females (Miller & Bichsel, 2004) and also among pre-school teachers (Gresham, 2007). In addition, studies have shown that there are three main consequences: Teachers who show higher levels of math anxiety are less competent in different mathematical domains (e.g., Rayner, Pitsolantis & Osana, 2009), avoid mathematical situations (e.g., Chinn, 2012), and transfer their own math anxiety to their students (Beckdemir, 2010). Hence, different kinds of interventions, such as systematic desensitization and cognitive restructuring, were assumed to reduce math anxiety in teacher training and were investigated as such (e.g., Hembree, 1990). However, nothing is known about whether the relationship between mathematical competence and math anxiety occurs on a generalized level or on a situation-specific level.

Latent State-Trait Theory

Studies that have examined the relationship between mathematical competence and math anxiety have indicated that both constructs can be seen as *traits*, meaning that these constructs are stable and consistent over time and can be generalized across various situations (Liebert & Liebert, 1998). For example, Weinert (2001) defined competence as the ability to successfully master problems in variable situations. In addition, other evidence has suggested that mathematical competence is a stable personality characteristic (Aunola et al., 2004). According to Klieme, Hartig and Rauch (2008, p. 5), competence as a trait provides the chance to examine competence characteristics in larger groups of persons because inter-individual differences in achievement are assumed to be caused only by the trait (*dispositionism*, Epstein, 1984). However, Mischel (1968) assumed that situation-specific influences may also affect the measurement of constructs (*situationism*). This implies that these constructs have unstable and specific portions (*occasion-specifics*) that are sensitive to situations.

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Steyer, Schmitt and Eid (1999) pointed out that "measurement does not take place in a situational vacuum" (p. 389). There may be different situational effects that influence measurement (cf. Anastasi, 1983) with the result that measures may differ due to the situational specificity of the measurement occasion. "The term 'situation' refers to the unobservable psychological conditions that might be relevant for the measurement of the construct considered" (Steyer, Schmitt & Eid, 1999, p. 394). With regard to the present study, such unobservable conditions might be fatigue, attitudes toward mathematics, or psychophysiological parameters. Observable situational factors (e.g., the composition of the class or material that may prime math anxiety) are purposefully not varied in such studies but are rather held constant.

Steyer, Partchev, Seiß, Menz and Hübner (2000) suggested that achievement scores also contain significant amounts of occasion-specific variance. From a theoretical point of view, it is assumed that anxiety consists of both parts (Spielberger, 1972). Furthermore, math anxiety is seen as a reaction to situational aspects (Ashcraft, 2002). Math anxiety measured as a trait was correlated with general trait anxiety and state anxiety. By systematically manipulating the situation, occasion-specific effects occurred (Hembree, 1990; Goetz, Bieg, Lüdtke, Pekrun & Hall, 2013).

The Latent state-trait theory (LST) allows (1) for the investigation of dispositional differences among persons ("traits") and (2) for them to be separated from occasion-specific effects as well as from effects of interactions of traits and occasions on obtained scores (Steyer, Schmitt & Eid, 1999; Geiser & Lockhart, 2012). LST examines these traits and occasion-specifics with regard to variability, meaning that these two concepts can be attributed to inter-individual differences. Traits develop across the lifespan (i.e. characteristics of a person can increase or decrease). Thus, developmental processes do not represent occasion-specifics.

The LST has already been applied in numerous fields in psychology (Geiser & Lockhart, 2012), but it has rarely been applied in educational research (see Eid & Hoffmann, 1998, for its only previous application in educational research concerning students' interest in the topic of radioactivity). To apply the LST, at least two occasions and at least two test halves (Steyer, Schmitt & Eid, 1999) are required to investigate trait and occasion-specific effects (the latter including purely occasion-specific effects and the interaction of trait and occasion).

The basic assumption according to Eid and Diener (2004) is that the achievement of an individual (state variable S) can be decomposed into an occasion-unspecific variable (trait variable T) and an occasion-specific deviation variable (OS). Considering the measurement error E of an observed variable Y, it is assumed that Y can be decomposed into S and E. With respect to different occasions and different traits measured at each occasion, the following decomposition follows:

$$Y_{ki} = T_i + OS_k + E_{ik}$$

where k refers to the kth occasion of measurement and i refers to the ith trait measured at occasion k. Eid and Diener (1999) referred to this model as the multistate-multitrait model (MSMT). This model is one of the most popular models in LST research, and it allows a researcher to investigate the different variance components of traits, occasion-specifics, and measurement error and is thus based on classical test theory (see Fig. 1). MSMT models do not need additional method factors because of their indicator-specific trait factors (Geiser & Lockhart, 2012).

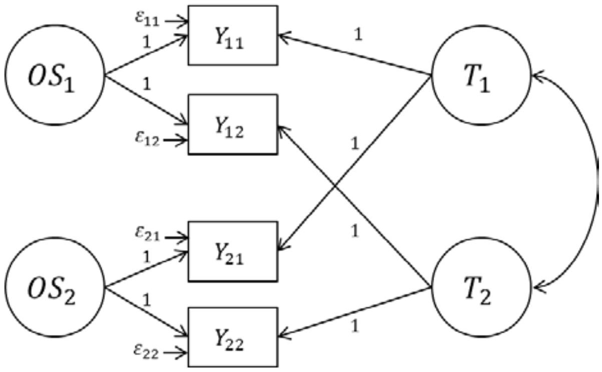

Fig. 1. *Multistate-Multitrait Model.*

LST modeling takes place in the framework of structural equation modeling. Modeling in terms of LST requires strong factorial invariance (Meredith, 1993), which means that the factor structure, factor loadings, and intercepts are not allowed to differ significantly across measurement occasions (Geiser et al., in press). The basic assumption of an MSMT model is: The occasion-specific variable OS_k is common to all traits i measured at occasion k. This means that OS_k accounts for the effects of situational aspects and the interaction of trait and occasion k at the same time. The next assumption is that all occasion-specific variables are uncorrelated. Consequently, it is assumed that the latent trait variables T_i explain stability across occasions and is therefore not indexed with k. Whether an observed variable (indicator) contains significant amounts of occasion-specific or trait variance is in the end an empirical question of model fit.[2]

Research Questions

The present study examined the relationship between mathematical competence and math anxiety in prospective pre-school teachers. The state of research (e.g., Ma, 1999) suggests a moderate negative correlation between these two constructs. However, almost nothing is known about whether this negative relationship occurs on a stable, generalized level or on an occasion-specific level.

The present study also applied LST to enhance our understanding of the nature of mathematical competence in prospective pre-school teachers. From a psychometric point of view, the study represents a construct validation of the competence test because theoretical assumptions and practical procedures in competence research follow from the idea that mathematical competence can be viewed as a trait.

Thus, the purpose of this study was to close both research gaps with respect to prospective pre-school teachers by applying the well-established LST method. The main research questions were therefore, (1) Does this mathematical competence test actually measure mathematical competence as a trait as intended? A confirmation would mean that this measure should be influenced only by personal characteristics and not by natural variations; and (2) What is the relationship between mathematical competence and math anxiety with respect to LST? More precisely, this research question asks whether correlational relationships exist on only the trait level, on only the occasion-specific level, or on both levels.

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[2] More details about LST and its methodological implications can be found in Eid and Diener (2004).

Method

Participants

354 prospective pre-school teachers were assessed twice within a time frame of two to three weeks. They came from 16 classes belonging to five vocational schools in the greater areas of Berlin and Bremen/Lower Saxony. The participants' mean age was M=22.9 years (SD=2.1 years). About 83% of the participants were female. The participants differed in their years of training: 41.5% were tested during their first year of training, 33% during their second year of training, and 25.5% during their third year of training. 17.5% of the participants had at least one missing value on one variable.

Instruments

Mathematical competence was measured with a test developed in the KomMa project. This paper-pencil test consists of 24 items combining the mathematical domains and processes described above. Most of the items are presented in a multiple-choice format and some in an open-response format. The interrater reliability (Kappa coefficient) for open-response items was between .95 and .99. All items were coded dichotomously (right/wrong). Results of the pilot study confirmed factorial validity in that the test was able to distinguish between the four domains as hypothesized with six items for each domain. The reliability of each dimension/domain as measured by Cronbach's alpha ranged from α=0.80 to 0.86. The content validity of the test was also confirmed through a systematic expert review process (Jenßen et al., 2013).

The Mathematics Anxiety Scale-Revised (MAS-R; Bai et al., 2009) was used to examine math anxiety. The questionnaire contains 14 items of which six are positive statements, for example "I find math interesting," and eight are negative statements, for example "Mathematics makes me feel nervous." Participants provide their answers on a five-point Likert scale ranging from "totally agree" to "totally disagree." The positive statements have to be reverse scored so that a high score indicates high anxiety. The questionnaire has satisfactory reliability (Cronbach's α=0.87) and is considered valid (Bai, 2011).

Procedure

The assessment took place during regular instruction times and at the same time for each class. First, participants completed the MAS-R. Second, to avoid priming effects, participants completed other instruments (e.g., about their mathematical pedagogical content knowledge or their self-efficacy) before they began working on the mathematics test. This procedure was similar at occasion 1 and occasion 2.

Data analysis

A series of structural equation models was applied to examine the research questions. First, an MSTM of mathematical competence was estimated. Four indicators were used to represent the four subdimensions of the test. Second, an MSTM of math anxiety was estimated. Two indicators were built: one for the negative items and one for the positive items. For each model, strong factorial invariance was examined, and occasion-specific factors were tested. In a third step, we examined the complex relationship of math anxiety and mathematical competence in an integrated LST model. All statistical analyses were computed with the Mplus 5.2 software package and took the clustered data structure into account (MLR estimator; TYPE=complex) with the 16 classes representing the second level (Muthén & Muthén, 2007). Missing data were handled by using the FIML procedure.

Results

Raw Scores

The raw scores for each (sub-)trait and each occasion are reported in Table 1. The mathematical competence score had a potential range of 0 to 24, and the scores from each mathematical dimension could range from 0 to 6. The Mathematics Anxiety Scale - Revised score could range from 14 to 70. The positively phrased math anxiety score could range from 6 to 30 and the negatively phrased math anxiety score could range from 8 to 40.

Table 1

Raw Scores of the Mathematical Competence and Anxiety (Sub-)Scales.

	Occasion 1		Occasion 2	
Measurement	M	SD	M	SD
Mathematical Competence (MC)	11.39	4.27	10.93	4.40
Number and Operations (NO)	3.29	1.42	3.06	1.44
Geometry (GE)	2.74	1.50	2.69	1.53
Quantity and Relation (QR)	2.65	1.19	2.53	1.17
Data, Combinatorics, and Chance (DC)	2.77	1.33	2.60	1.34
Mathematics Anxiety Scale - Revised (MAS-R)	43.77	10.71	43.19	10.18
Positively phrased subscale (MAp)	19.86	5.32	19.46	5.26
Negatively phrased subscale (MAn)	23.91	6.71	23.73	6.25

Mathematical Competence

Four trait variables were specified according to the four mathematical domains representing mathematical competence. Each trait variable was specified by two indicators (one indicator per occasion), and each indicator was an item parcel that was formed by summing six items.

We first examined measurement invariance across occasions. Results indicated that all factor loadings could be restricted to 1. However, the intercept of the indicator “number and operations” at occasion 2 was -0.14 and significantly different from 0 ($p<0.05$); all other intercepts were fixed to zero. A first estimation of the basic MSMT model revealed an acceptable model fit ($\chi^2(19)=30.46$, $p=0.046$, RMSEA=0.042 [0.01;0.07], SRMR=0.02, CFI=0.99) but also negative variances of the occasion-specific variables. Therefore, these variances were fixed to zero, and the model was re-estimated. The modified MSMT model for mathematical competence fit the data well, $\chi^2(21)=30.93$, $p=0.07$, $\chi^2/df=1.5$, RMSEA=0.037 [0.00;0.06], SRMR=0.03, CFI=0.99.

The estimated parameters of this model are presented in Table 2. The correlations between the four subdimensions ranged from .6 (quantity and relation with data, combinatorics, and chance) to .8 (number and operations with geometry). All correlations were significant ($p<0.001$). The amount of variance explained by the indicators ranged from .66 (number and operations at occasion 2) to .74 (data, combinatorics, and chance at occasion 2).

Math Anxiety

Two trait variables were specified: one for the negatively phrased math anxiety items and one for the positively phrased math anxiety items. Just as for the mathematical competence model, each trait variable was specified by two indicators that represented parcels that were formed by summing the corresponding items.

Again, measurement invariance was tested first. All factor loadings could be restricted to 1. The intercept of the negative indicator was fixed to zero, and the positive indicator at occasion 2 had a significant intercept of -0.07 ($p<0.05$). A basic MSMT model was tested. The model fit was good ($\chi^2(2)=2.24$, $p=0.3258$, RMSEA=0.02 [0.00;0.11], SRMR=0.01, CFI=1.00). Since the data indicated negative or nonsignificant occasion-specific variances, we estimated a modified MSMT model with occasion-specific variances fixed to 0; this model fit the data well ($\chi^2(4)=3.65$, $p=0.894$, χ^2/df=0.9, RMSEA=0.00 [0.00;0.08], SRMR=0.01, CFI=1.00.

The estimated model parameters are presented in Table 2. The correlation between the positive math anxiety statements in their reversed version and the negative ones was 0.67 ($p<0.001$). Thus, the two indicators accounted for different facets of math anxiety. The amount of variance explained by the indicators ranged from 0.83 (negative indicator at occasion 1) to 0.88 (positive indicator at occasion 1).

Table 2
Estimated model parameters.

	Positively phrased Math Anxiety	Negatively phrased Math Anxiety	Number and Operations	Geometry	Quantity and Relation	Data, Combinatorics, and Chance
$Var(T)$	24.60* (2.35)	36.29* (2.38)	1.32* (0.16)	1.64* (0.16)	0.98* (0.13)	1.29* (0.17)
$Mean(T)$	19.89* (0.31)	23.87* (0.27)	3.24* (0.12)	2.69* (0.13)	2.56* (0.08)	2.62* (0.09)
$Var(OS_1)$	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)
$Var(OS_2)$	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)	0 (fixed)
$Var(\varepsilon_1)$	3.47* (0.68)	7.58* (1.31)	0.73* (0.08)	0.61* (0.06)	0.42* (0.06)	0.52* (0.06)
$Var(\varepsilon_2)$	3.55* (0.62)	5.78* (1.63)	0.68* (0.09)	0.65* (0.07)	0.42* (0.04)	0.45* (0.05)

Note. * p<0.001, T=indicator-specific trait variance, OS_k=occasion-specific variance at occasion k, ε_i=residual variable of indicator i, standard errors in parentheses.

Final Model Representing the Complex Relationship of Mathematical Competence and Math Anxiety

To model the complex relationship between the different domains of mathematical competence and the different subdimensions of math anxiety, the two models were integrated into an overall MSMT model. This MSMT model was fit to the data, $\chi^2(49)=74.46$, $p=0.011$, χ^2/df=1.5, RMSEA=0.04 [0.02;0.06], SRMR=0.03, CFI=0.99. Considering the complexity of the model, the fit could be regarded as acceptable, although the deviance in the chi-square value was still significant (Schermelleh-Engel, Moosbrugger & Müller, 2003).

The correlations between mathematical competence and math anxiety are presented in Table 3. All correlations between the latent trait variables were significant, negative, and moderate in size. The highest correlation was found between geometry and the positively phrased trait of math anxiety. The lowest correlation was found between the negatively phrased trait of math anxiety and data, combinatorics, and chance. The positive math anxiety statements appeared to be more strongly related to mathematical domains than the negative ones. Also, number and operations as well as geometry appeared to be more strongly associated with math anxiety than the other domains. Some of the differences in the correlations were significant ($p<0.05$).

Table 3
Variances (diagonal), covariances (lower triangular matrix), and correlations (upper triangular matrix) for the latent occasion-specific and latent trait variables.

	NO	GE	QR	DC	OS_{MC1}	OS_{MC2}	MAp	MAn	OS_{MA1}	OS_{MA2}
NO	1.32	*0.80*	*0.75*	*0.67*	*0.00**	*0.00**	*-0.36*	*-0.30*	*0.00**	*0.00**
GE	1.18	1.65	*0.71*	*0.60*	*0.00**	*0.00**	*-0.38*	*-0.34*	*0.00**	*0.00**
QR	0.85	0.90	0.98	*0.60*	*0.00**	*0.00**	*-0.30*	*-0.27*	*0.00**	*0.00**
DC	0.87	0.89	0.67	1.29	*0.00**	*0.00**	*-0.32*	*-0.24*	*0.00**	*0.00**
OS_{MC1}	0.00*	0.00*	0.00*	0.00*	0.00*	*0.00**	*0.00**	*0.00**	*0.00**	*0.00**
OS_{MC2}	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	*0.00**	*0.00**	*0.00**	*0.00**
MAp	-2.05	-2.41	-1.50	-1.81	0.00*	0.00*	24.58	*0.67*	*0.00**	*0.00**
MAn	-2.10	-2.61	-1.60	-1.61	0.00*	0.00*	19.97	36.34	*0.00**	*0.00**
OS_{MA1}	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	*0.00**
OS_{MA2}	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*

Note. * fixed, all correlations with the latent trait variables were significant ($p<0.001$), NO = Number and Operations, GE = Geometry, QR = Quantity and Relation, DC = Data, Combinatorics and Chance, MAp = positively phrased math anxiety, MAn = negatively phrased math anxiety, OS_{MCk} = occasion-specific variable for mathematical indicators at occasion k, OS_{MAk} = occasion-specific variable for math anxiety indicators at occasion k.

Summary and Discussion

The aim of the present study was to shed light on the relationship between mathematical competence and math anxiety in prospective pre-school teachers. In addition, the present study was intended to demonstrate the usefulness of LST. It can be used for the construct validation of competence tests or to examine complex relationships. It is possible to identify indicators representing a trait rather than occasion-specific constructs and vice versa with the help of LST. Therefore, LST can also be used in test construction.

In the present study, the data were in line with the theoretical assumptions about mathematical competence as a trait and thereby supported the construct validity of the KomMa test. Math anxiety as assessed here also seems to be a trait. The results basically indicate that prospective pre-school teachers differ inter-individually in their trait characteristics. These differences in mathematical competence and math anxiety cannot be attributed to situational factors but rather to stable person characteristics (Klieme, Hartig & Rauch, 2008, p. 5).

The results of the present study imply that, as long as the contextual conditions are quite similar across situations and not too much time goes by, no occasion-specific variability can be found in everyday settings in math anxiety or in mathematical competence. Future research is needed to determine whether this result can be generalized across other settings, in particular to those with varying conditions.

From the point of view of LST, the results of the present study on mathematics competence resemble the results of Danner, Hagemann, Schankin, Hager and Funke's (2011) study in which LST modeling was applied to different intelligence measures. In their study, significant occasion-specific variability was not found either. One might therefore cautiously hypothesize that in general, cognitive constructs are not comprised of situational occasion-specific variance (Steyer et al., 2000).

Since math anxiety also seems to be a trait if assessed with the MAS-R, it might be suggested that math anxiety has characteristics that are similar to the stable anxiety schema in anxiety disorders (Ashcraft, 2002). However, it might again be the case that occasion-specific variance in math anxiety occurs when situations are systematically varied (Goetz et al., 2013).

Similar to Ma's (1999) meta-analysis, our data revealed a moderate negative relation between math anxiety and mathematical competence. These relations existed in all mathematical domains. In addition, our study was the first to present evidence that math anxiety is a substantial phenomenon in pre-school teachers in Germany. Our examination of measurement invariance showed a slight but significant decline in competence in "number and operations" at occasion 2. This result might be due to a lack of motivation to work on the tests at occasion 2. Studies have indicated that motivational aspects play an important role in the complexity of mathematical competence and math anxiety (Zakaria & Nordin, 2008). Simultaneously, math anxiety declined significantly at occasion 2 for the positively phrased indicator. A possible explanation might be that participants were less anxious about mathematics because of their experiences at occasion 1 (Beckdemir, 2010).

A limitation of the present study is its representativeness. The sample did not reflect the full heterogeneity of prospective pre-school teachers' training because it did not capture the full range of years of training and did not represent prospective pre-school teachers from federal states other than Berlin and Bremen/Lower Saxony. Thus, the generalizability of our findings is limited to the groups represented in our sample. Future research should examine whether the same findings apply to other groups of prospective pre-school teachers.

Conclusions

If the results of the present study can be replicated and a stable relationship between math anxiety and mathematical competence can in fact be supported, interventions that are designed to reduce math anxiety in order to minimize its negative effects on achievement should focus on the stable facets of math anxiety. From research on anxiety disorders and the general theoretical assumptions about anxiety, it is well-known that cognitions play a role in shaping the stable part of anxiety (e.g., Morris, Davis & Hutchings, 1981). Therefore, attempting to modify the cognitive parts of the math anxiety scheme (e.g., cognitive restructuring) might be a worthwhile approach. Hembree (1990) showed the effectiveness of such an intervention in comparison with other interventions that focused on situational aspects such as relaxation training.

Further research is needed on the effects of the mathematical competence and math anxiety of pre-school teachers on their interactions with children and the development of children's mathematics achievement during pre-school. Possible research questions are whether math anxiety is transmitted from teachers to children or whether pre-school teachers avoid mathematical situations when they are highly anxious. Furthermore, pedagogical content knowledge and pedagogical knowledge are important facets of pre-school teachers' professional competence too. However, little is known about how they are related to math anxiety, and therefore, further research is needed.

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