EFFECTS OF TEXTBOOKS ON MATHEMATICS TEACHING AND LEARNING IN GERMAN PRIMARY SCHOOLS

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Empirical studies show that textbooks have an influence on teachers' instruction and that instruction affects students' achievement. However, little research has been conducted on the whole causal chain: the influence of textbooks on students' achievement mediated by teachers' instruction. We report findings from a re-analysis of a two-year longitudinal study with 75 primary school classes. Results of multilevel analyses indicate that the didactical structure and the content of a textbook influences students' achievement. Moreover, we provide evidence that the effect of the textbook content is mediated by instruction.

THEORETICAL BACKGROUND

In the last decades, a growing body of research has directed the attention to mathematics textbooks. Based on the assumption that textbooks have a substantial influence on the teaching and learning of mathematics, different kinds of research questions and methodologies were elaborated in mathematics education research (see the overview in Fan, Zhu, & Miao, 2013). Among others, textbooks were considered as artefacts with very different functions, for example, as learning material for students, as task collections or stimulus for teachers' lesson planning, or as tool for education administrations to communicate the intended curriculum (Fan et al., 2013). Accordingly, textbook research has addressed various questions concerning these functions, for example, the role of textbooks on teachers' lesson preparation and instruction (Krammer, 1985; Lepik, Grevholm & Viholainen, 2015) or the influence of teacher characteristics on the effects of textbooks on instruction (Remillard, 2005).

The role of textbooks for teaching and learning: empirical results

In this section, we present exemplary empirical results which illustrate aspects of the interaction between the curriculum, textbooks, teachers and the learning activities of students. First we address results from studies investigating the effects of textbooks and, secondly, we elaborate on the question whether teacher characteristics (as moderator variables) influence textbook effects on the mathematics classroom.

Effects of textbooks on mathematics teaching and learning

Several studies, including international large scale assessments, showed that teachers frequently use textbooks for their instruction. For example, in TIMSS 2011 about 75% of the primary school teachers reported that they use the mathematics textbook as primary basis for their instruction (Mullis, Martin, Foy, & Arora, 2012). Similar results were presented by Lepik et al. (2015) for 402 secondary teachers from Estonia, Finland

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and Norway. Comparisons of the influence of different factors on the teaching content indicated that the textbook has the strongest influence (e.g., Mullis et al., 2012).

These findings suggest a relation between textbooks and teachers' instruction. This assumption is supported by results from TIMSS 1995 which indicate a positive correlation between the space a topic covers in a textbook and the instructional time teachers using this textbook have dedicated to this topic in mathematics classroom (Schmidt et al., 2001). A classroom observation study by Krammer (1985) with 50 eighth-grade teachers provides evidence for a consistency between textbook features and teaching practices. The three teacher groups corresponding to three different textbooks significantly differ in their frequency of posing higher-order questions or the students' perception of remedial help. However, it is not clear if the textbook influenced the teachers or if teachers chose a textbook which suits their teaching style.

Van Steenbrugge, Valcke, and Desoete (2013) conducted one of the rare quantitative studies on the effects of mathematics textbooks on students' achievement. The cross-sectional study included 1579 students (grade 1 to 6) and their 90 teachers using five different textbooks. The authors did not find evidence for a substantial differential effect of textbooks on students' mathematics performance when controlling for teachers' experience. Törnroos (2005) also examined the influence of textbooks on students' achievement using data from TIMSS 1999 in Finland (nine different mathematics textbooks series used in 161 Finish secondary schools). It turned out that the amount of opportunities to learn a textbook provided specifically for the content of TIMSS items was significantly correlated with students' performance in the TIMSS test. In contrast to the results from van Steenbrugge et al. (2013), these findings suggest that textbooks have an effect on student achievement. Törnroos (2005) hypothesized that the textbook effect on student achievement is mediated by the teaching content.

Teacher characteristics as moderators of textbook effects

As previously mentioned, there is evidence for a connection between the textbook content and the content realized by teachers in classroom instruction (Schmidt et al., 2001). Case studies indicate that there are different patterns in textbook use so that use of the same textbook can result in a different quality of instruction (Fan et al., 2013). Hence, it seems to be promising to examine teacher characteristics as moderators of this relation. According to the review article of Remillard (2005) teachers' beliefs play a substantial role for teachers' decisions concerning the selection, design and enactment of mathematics tasks as well as the curriculum mapping. Moreover, there are plausible reasons for the influence of teacher knowledge on textbook use, though clear empirical evidence is still missing. In a study with 48 teachers on the quality of curriculum implementation, Stein and Kaufman (2010) did not find a correlation between teacher capacities (e.g., knowledge, professional development activities) and the quality of curriculum implementation (indicator: maintenance of cognitive demand from material to enactment phase of the lesson). In contrast, Hill and Charalambous (2012) presented a series of case studies indicating an influence of teacher knowledge

on the use of curriculum material. They hypothesize that instructional quality of teachers with low professional knowledge depends on the quality of the used curriculum material (which especially comprises the textbooks) whereas teachers with high professional knowledge are able to compensate low quality curriculum material.

RESEARCH QUESTIONS AND METHOD

The previously presented research indicates that there are still open questions concerning the effect of textbooks on students learning in mathematics. Many research results are based on small scale studies using qualitative methods (cf. the overview in Fan et al., 2013). These results provide valuable insight into the interplay between textbooks, teacher and instruction and should be supplemented by corresponding results of quantitative studies. Only a few studies investigate the effects of textbooks on student achievement. Especially, we are not aware of longitudinal studies. Finally, most studies address textbooks from higher grade levels (> grade 5) and effects of textbooks in the first grades are not well investigated. To contribute to this field of research, we conducted a re-analysis of a data set from a longitudinal study (details below) which allows examining the following research questions:

1. Does the textbook used by primary mathematics teacher have an effect on the teaching content and on students' achievement at the beginning of primary school?
2. Are the effects of mathematics textbooks moderated by teacher characteristics?

Research context

Basis for our analysis is an existing data set from a large two-year longitudinal study with primary school students from one federal state in Northern Germany. The sample consists of $N = 2737$ students from 123 classes in 40 schools. It comprises student data from the beginning of grade 1 when students entered school (normally at the age of 6 years) to the end of grade 2. The original aim of the study is to address students' competence development in arithmetic which is the heart of primary mathematics.

There are specific characteristics of the national educational context framing the research and the interpretation of the results. In Germany, each federal state has a statewide curriculum which describes for each grade the content, skills and abilities teachers must address. The mathematics textbooks mirror these curricula and primary schools can select a mathematics textbook series for their grades 1-4. Our data set covers schools from one federal state following the same curriculum and using different mathematics textbooks. Hence, it is possible to investigate effects of different textbooks on teaching content and student achievement (cf. research question 1). Moreover, many primary school teachers in Germany teach mathematics without formal qualifications in mathematics and mathematics education. According to Richter, Kuhl, and Reimers (2012), students taught by these teachers show a lower mathematics achievement. Hence, we address teacher qualification as moderator for textbook effects on teaching content and student achievement (cf. research question 2).

Textbooks

In a subsample of 75 classes four popular textbook series (denoted by A, B, C, D) were used. All textbooks series show a variation in the space used for the curricular topics and the emphasis of learning goals but they all mirror the prescribed curriculum. There are two striking features which allow a grouping of the textbooks for our study.

1. In contrast to textbook series A, B and C, series D prescribes a linear order which the students should follow when learning the arithmetical content. For grade 1, textbook series D consists of six and for grade 2 of five consecutively numbered booklets. For example, the first booklet in grade 1 covers the numbers 1-6, the second addition and subtraction with numbers 1-6, the third the numbers 7-13, the fourth the number domain 1-20 and related problems, the fifth addition and subtraction in the domain 1-20 etc. In each booklet the learning content is structured in small steps and students should work individually page by page on the presented mathematics problems. New concepts (numbers, operations) are introduced by a quick transformation from an iconic to the symbolic representation. Each problem type is dedicated 1-2 pages for practicing and connections between mathematically related topics are hardly addressed. The textbooks of series A, B and C do not prescribe in detail a specific learning trajectory for students. Arithmetic concepts are mostly introduced following an elaborated transformation from iconic and symbolic representations. Learning opportunities for procedural and conceptual knowledge are balanced and connections between related arithmetic topics are addressed. Based on these strong differences, we compared students taught by textbook series D with students taught by textbooks from series A, B or C to examine effects of the didactical structure of textbooks.

2. Another striking difference between the textbooks for grade 1 is a very specific content aspect: textbooks from series A and C do not introduce the number line as a representation in grade 1 (in these textbooks it appears at the beginning of grade 2 for the first time). In contrast, textbooks from series B and D suggest the introduction of the number line in the middle of grade 1. All textbooks address ordinal aspects of numbers (by counting or by ordering numbers). Based on these differences, we compared effects of textbook series A and C with effects of series B and D on the implemented teaching content and on student achievement related to the number line.

Instruments, data collection and statistical analysis

Student and teacher data were collected by different tests and questionnaires. Data for controlling the learning prerequisites of the students (basic numerical skills, basic language skills, general cognitive abilities) were measured with approved standardized instruments at the beginning of grade 1. Data for the individual learning progress were collected at the end of grade 1 and 2 with grade-specific arithmetic tests on conceptual and procedural knowledge. The two tests on procedural knowledge comprised 57 and 45 items addressing e.g., doubling, halving, part-whole relations, addition, subtraction in the number domain 1-20 or 1-100 (depending on the grade). The two tests on

conceptual knowledge with 12 and 29 items covered grade-specific arithmetic content emphasizing e.g., models of subtraction, multiplication, division; comparing numbers, place value relations). Moreover, there was data from a number line test with eight items administered in the second half of grade 1 (allocating four numbers on a semi-structured number line and identifying four numbers on a structured number line). The data of each test were scaled based on Item-Response-Theory and all scales showed an acceptable reliability (EAP-PV between .79 and .96).

The teachers were asked for the textbook they used as well as for their teacher qualification (educated as mathematics teacher or not). Since the number line test was administered in the second half of grade 1 during the school year, the teachers were asked to what extent they already had addressed the number line at that time in their previous teaching. We took this as an indicator of teaching content implementation.

We conducted multilevel analyses which take into account the nested structure of the sample (students in classes). We included the variables for learning prerequisites at school entrance on the individual level and as aggregated value on the class level (as an indicator of group composition). Textbook type, implemented teaching content and teacher qualification were included on class level. For the number line context we analyzed the mediation *textbook* $\rightarrow$ *implemented teaching content* $\rightarrow$ *student achievement* by a multilevel 2-2-1-mediation structural equation model (following Preacher, Zyphur, & Zhang, 2010).

RESULTS

To answer research question 1 we analyzed the effect of the didactical structure of the textbook on students' achievement. We considered the influence of textbook series A, B and C (textbook = 0) versus textbook series D (textbook = 1) on conceptual and procedural knowledge at the end of grade 1 and grade 2. Due to space limitation we only describe the relevant results for grade 1 and present a compact form of the multilevel analysis output for grade 2 (table 1).

At the end of grade 1 only 12% (respectively 13%) of the variance of students' achievement in procedural (conceptual) knowledge can be explained by the class level (ICC in the null model). It turns out that the teacher qualification and the textbook have no direct significant influence on the students' conceptual or procedural knowledge. However, there is a significant interaction effect teacher qualification × textbook on students' procedural knowledge ($\beta = -.55$, $SE = .18$, $p < .001$) explaining 29% of the variance on class level. There is no such interaction effect for conceptual knowledge.

At the end of grade 2, 15% of the variance of students' achievement in procedural and in conceptual knowledge can be explained by the class level (ICC in the null model). Table 1 shows the multilevel models for conceptual and procedural knowledge. In both cases textbook D has a direct negative effect. For the conceptual knowledge students of non-certified teachers show a low achievement independent of the textbook.

	Conceptual knowledge	Procedural knowledge

		β (*SE*)	β (*SE*)
Individual level	Cognitive abilities	.27** (.04)	.35** (.04)
	Basic numerical skills	.19** (.04)	.20** (.04)
	Language skills	.14** (.03)	.09** (.03)
	R^2	23%	29%
Class level	Cog. abilities (aggregated)	.35* (.17)	.39* (.18)
	Basic numeric. skills (agg.)	-.04 (.17)	-.08 (.20)
	Language (aggregated)	.12 (.16)	-.10 (.16)
	Teacher qualification	-.29* (.16)	-.05 (.14)
	Textbook	-.50** (.14)	-.28* (.14)
	Teacher qualification × Textbook .	14 (.18)	-.32 (.18)
	R^2	46%	51%

** $p < .01$, * $p < .05$; *textbook*: A, B & C = 0; D = 1; *teacher qualification*: certified mathematics teacher = 0, non-certified mathematics teacher = 1

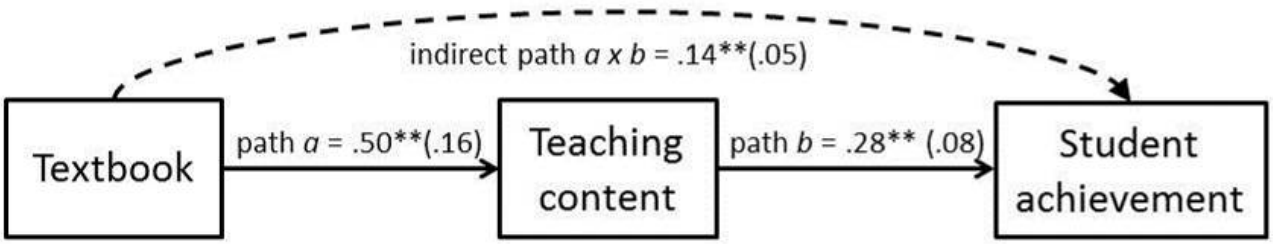
Table 1: Multilevel models for procedural and conceptual knowledge

For research question 2 we analyzed for the topic number line whether there is an effect of the textbook on students' achievement which is mediated by the teaching content. According to Preacher et al. (2010) the adequate model for nested data is a multilevel structural equation model. As presented in Figure 1, there are significant direct effects *textbook* → *teaching content* and *teaching content* → *student achievement* as well as a significant indirect effect *textbook* → *student achievement* mediated by *teaching content*. Like in the models before the three variables for learning prerequisites are controlled on both levels. Here teacher qualification shows no influence.

DISCUSSION

The results of our quantitative study with grade 1 and 2 students indicate that the textbook has a substantial influence on students' achievement in arithmetic in the first years of primary school. At least two different aspects of textbooks are relevant for this effect: the content covered by the textbook and its didactical structure.

From the mediation model presented in Figure 1 we conclude that the influence of the textbook content on students' achievement is mediated by the learning opportunities (i.e. learning content) that are offered to the students in the mathematics classroom. As described above, the textbook content influences the content teachers offer in mathematics lessons (e.g., Schmidt et al., 2001) and the vast majority of primary teachers report that they use textbooks as primary resource for teaching preparation (Mullis et al., 2012). Törnroos (2005) assumed learning opportunities as mediator for textbooks effects on secondary students' achievement but he had no data about the content taught to the students in his sample. Our results provide the missing evidence.



(RSMEA = .015, CFI = .99, TLI = .99, $SRMR_W$ <.001, $SRMR_B$ = .06);
textbook: A & C = 0; B & D = 1; *teaching content* as (i) allocating numbers on a semi-structured number line and (ii) identifying numbers on a structured number line: 0 = number line not addressed; 1 = one of two aspects addressed; 2 = both aspects addressed.

Figure 1: Mediation in a 2-2-1 design tested as multilevel structural equation model

In addition to the content aspect, our results in table 1 show that the didactical structure of a textbook, which suggests specific learning trajectories and learning activities, has a substantial impact on student achievement. Already Krammer (1985) presented findings for the secondary level that the didactical orientation of a textbook has a certain consistency with the observed teaching and learning activities. In our sample we found that a textbook which strongly prescribes learning activities in a specific linear order has negative effects on conceptual and procedural knowledge at the end of grade 2. Interestingly, in grade 1 we found only a strong negative effect for procedural knowledge, which is moderated by teacher qualification. Our interpretation is that the grade 2 content in mathematics (number domain 1-100, place value system, multiplication and division) is much more challenging than the grade 1 content so that the influence of instruction and the textbook increases. Our grade 2 findings differ from that of van Steenbrugge et al. (2013) who did not find differential effects of textbooks on achievement. We think that these contrary findings can be explained by the fact that we included longitudinal data and that we compared two contrasting groups of specific textbooks. Finally, concerning the didactical structure of a textbook the teacher qualification has only a moderating effect in grade 1 (in grade 2 there is a direct effect). For the influence of teaching content on student achievement, we did not find a moderating effect of teacher qualification. A possible reason is that the dichotomous variable teacher qualification was to coarse as an indicator for teacher professional knowledge.

There are several limitations of our study. Since we re-analyzed an existing data set we were not able to administer specific instruments for our research. In particular, the questionnaires do not provide fine-grained data on the implementation of the teaching content or the teacher knowledge. Moreover, the result for the mediation (figure 1) is restricted to the content "number line" because student and teacher data is available for this topic in the data set. Despite of these limitations the data set has the advantage that it covers a large sample taught by the same curriculum and allows multilevel analysis

with an adequate explanatory power. Accordingly, we were able to supplement and further develop existing research on the effects of textbooks on students' learning.

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