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Which factors coincide with mathematical learning gains in bilingual classrooms? German language proficiency and mixed language use

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Although bilingual mathematical learning opportunities have often been requested for multilingual students, little quantitative evidence has been provided that activating two languages has measurable effects on learning gains. This study uses data from a bilingual teaching intervention to investigate which factors coincide most with the mathematical learning gains in conceptual understanding of fractions. Students' individual and family characteristics have been assessed and participation and language use have been coded in ~95h videotaped teaching-learning processes. A regression analysis shows that students' learning gains can best be explained by students' German language proficiency and their use of Turkish and mixed mode, while talking time did not coincide with learning gains. Thus, the connection of languages seems to be even more important for mathematical learning gains than the isolated use of home languages or active participation.

Keywords: Multilingual math learning, teaching intervention, supply-use-model, learning gains

Research gap on factors for effective multilingual mathematics learning

Many qualitative case studies illustrate benefits of activating multiple languages in mathematics classrooms (Planas, 2014). Multilingual resources have been shown to support mathematics learning and engaging students in discursive practices of problem solving, when drawing on multilingual everyday experiences (Domínguez, 2011). In fact, multilingual resources can support problem solving processes in general (Wagner, Redder, Kuzu, & Prediger, 2018), especially when students are highly proficient in their languages (Clarkson, 2006). Furthermore, the activation or acknowledgement of students' multiple languages can have a positive effect on students' agency (Norén, 2015). Summing up, multiple positive effects have been qualitatively identified. However, little *quantitative* evidence could so far be provided that bilingual interventions have *measurable* effects on the mathematical learning gains (Reljić, Ferring, & Martin, 2015).

In order to close this research gap on quantitative evidence, the project MuM-Multi conducted a randomized control trial with Turkish-German seventh graders comparing a bilingual and a monolingual German intervention aiming at conceptual understanding of fractions in small group teaching (Schüler-Meyer, Prediger, Kuzu, Wessel, & Redder, 2019a). The analysis showed that on average, mathematical learning gains in the bilingual intervention were comparable to the corresponding monolingual intervention. The differential analysis of learning gains shows that they were significantly higher for the students with high Turkish language proficiency (ANOVA: $F_{(\text{group x time})} = 4.49$, $p < .01$, $\eta^2 = .16$). Additionally, a strong variance in learning gains was found for the different small groups (for which Cohens *d* varied between -0.12 and 2.22). A first hypothesis was that these differences might be traced back to different intensity in Turkish modes.

Hence, this study systematically investigates the factors contributing to the effective use of multiple languages in mathematics classrooms. For this, a video analysis was conducted to capture students' language use (Schüler-Meyer, Prediger, Wagner, & Weinert, 2019b) with this research question:

Which factors in individual and family characteristics and students' language use significantly coincide with students' learning gains in the bilingual teaching intervention?

This research is framed by the supply-use-model (Brühwiler & Blatchford, 2011; Helmke, 2009), which is outlined in the next section, before the methods of the study and its results are presented.

Research framework: Supply-use-model for quantitatively capturing potentially relevant factors for bilingual interventions

The supply-use model (Brühwiler & Blatchford, 2011; Helmke, 2009) has often proven to be powerful in quantitative classroom research for modelling the factors that influence whether a *supplied* learning opportunity is really *used* to its full potential by students in a classroom and how this impacts the learning outcome. The assumption is that the relations between supply, use and outcomes (learning gains) can be influenced by context factors or students' individual or family characteristics. Figure 1 shows the general model and its adaptation for the current research (justified in detail in Schüler-Meyer et al., 2019b).

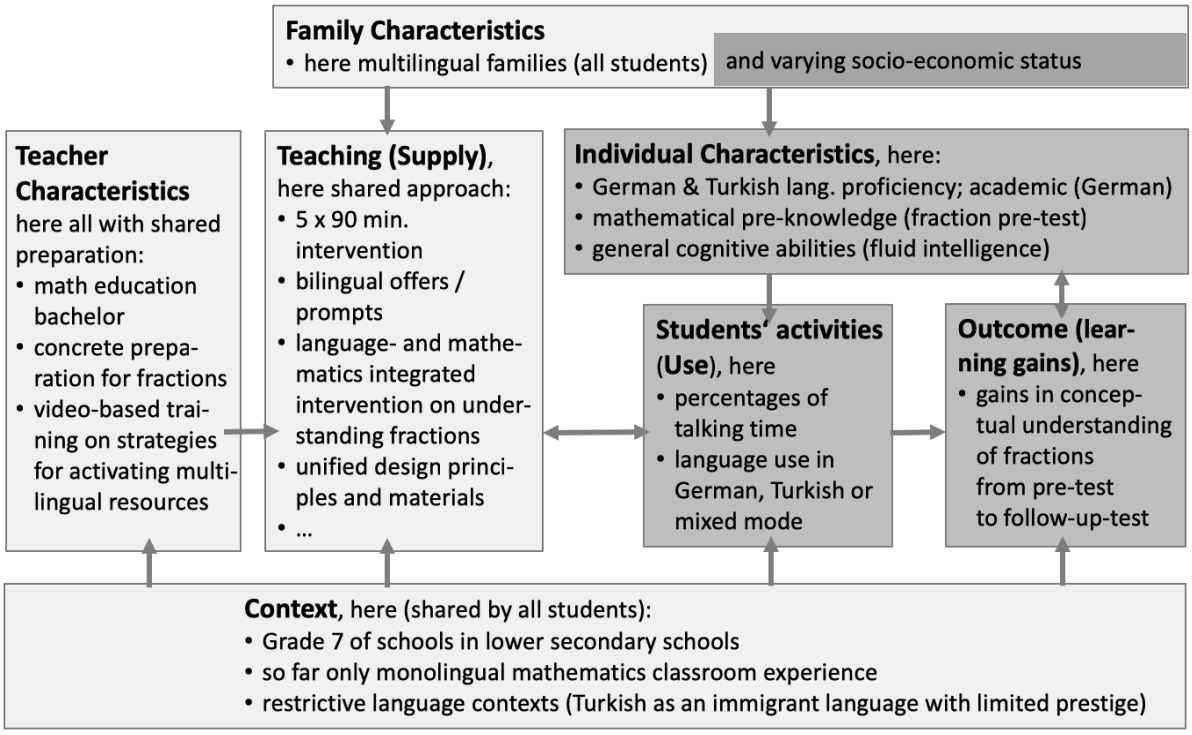

Figure 1: Supply-Use-Model adapted from Helmke (2009) by Schüler-Meyer et al. (2019b)
(factors held constant are colored in light grey, varying factors in dark grey)

Following the research question, we investigate the learning processes of multilingual seventh graders with equal conditions in the language context (cf. Schüler-Meyer et al., 2019a): All students stem from multilingual Turkish-German families (all factors held constant are colored in light grey in Figure 1), their shared language context is shaped by only monolingual math classroom experiences and the limited prestige of their home language Turkish. All small groups are taught by teachers which share many characteristics and preparations. They follow the same bilingual intervention with equal design principles and teaching materials, thus the *supplied* learning opportunities are held constant in the bilingual intervention on fractions.

The research question focuses on the individual *use* of supplied bilingual learning opportunities (in terms of percentage of individual talking time and language use) and students' *characteristics.* 'Percentage of individual talking time' was chosen as a use factor because active participation has often been qualitatively described as influencing learning gains (Gresalfi, Martin, Hand, & Greeno, 2009). The second *use factor concerns individual language use*: As all prior math experience was monolingual German, it was crucial to control whether students really use both of their languages. Like for most multilinguals, the bilingual modes are expected to be characterizable by mixed modes (e.g. various forms of Code-switching between German and Turkish), also for the second- and third-generation Turkish immigrant students (Auer, 2010).

Methodology of the study in the supply-use-model

Design of the bilingual teaching intervention

The investigated bilingual Turkish-German teaching intervention was designed to foster the conceptual understanding of fractions, which encompasses the part-of-whole concept, equivalence, and order of fractions. The intervention consists of five 90-minute weekly sessions and builds on three principles for fostering multilingual learning (cf. Schüler-Meyer et al., 2019a): (1) Providing rich contexts and problem tasks for language production (Domínguez, 2011); (2) macro-scaf–folding, which included encouraging the use of Turkish with bilingual teaching material, bilingual teaching practices (e.g. revoicing), explicitly addressing and developing the Turkish and German academic language, and (3) systematically relating registers (Prediger, Clarkson, & Bose, 2016).

Design of the overarching project MuM-Multi and video corpus for the current study

The randomized control trial (Schüler-Meyer et al., 2019a) was conducted in a pre-post-follow-up design with conceptual understanding of fractions as dependent variable. The family and individual characteristics mentioned in Fig. 1 served as control variables and the contrast between mono- and bilingual intervention served as the independent variable. The groups in the bilingual intervention were taught by trained Turkish-German speaking preservice teachers in small groups of 2-5 students, for 5 sessions of 90 minutes. This study focuses only on the bilingual intervention, for this 13 x 90 minutes video material of the third session was coded from 13 small groups. The third session in the middle of the intervention was chosen because teachers had developed their routines, and the students had a chance to overcome first barriers of using Turkish in the classroom.

Measures for data collection for the individual and family characteristics

At three measurement time points, several measures were administered:

- *Measures for students' conceptual understanding of fractions.* The test has 28 items to test for the understanding of the part-of-whole concept, equivalence, and order of fractions. The test has a satisfactory internal consistency with Cronbach's $\alpha = .83$ (28 Items, N=1120).
- *Measures for students' socioeconomic status and general cognitive abilities.* Students' socio-economic status was measured with the economic and reliable book scale ($r = 0.80$). The students' fluid intelligence was measured using an adapted matrix test BEFKI 7 (with Cronbach's $\alpha = .763$ in the initial full sample of N = 1124).
- *Measures for German and Turkish language proficiency.* Students' language proficiencies were measured by C-tests, which provide an economic and valid measure based on cloze texts. The C-tests are highly reliable: the Turkish C-Test with $\alpha = .874$ (N = 254) and the German C-Test with $\alpha = .774$ (N = 1122). Additionally, students' German academic language proficiency is measured with a test which assesses the use of nominalizations and other academic language features (BiSpra).

Initial sample and sample of the bilingual teaching intervention

The initial full sample encompasses N=1124 seventh-grade students from twelve secondary schools (48% female and 52% male). From the 303 Turkish speaking students, a subsample of 254 students self-selected themselves by accepting to work on the Turkish C-test (Table 1). For the intervention, students with a low conceptual understanding of fractions were selected (Cut-off of 28 points in the fraction test). This group consisted of N=128 students who were then stratified along the control variables and randomly assigned to the intervention groups. The sample of this study consisted of n=35 students who participated in the third sessions of the bilingual teaching intervention on fractions. Due to missing follow-up data, the statistical analysis has a sample of n=33 students.

	Initial sample (N = 1124)	**Bilingual subsample (N = 254)**	**Sample of this study (n = 35)**
Family characteristics			
Percentage of German-Turkish speaking students	27%	100%	100%
Socio-economic status (low, medium, high SES)	35%, 33%, 31%	38%, 30%, 31%	40%, 20%, 40%
Individual student characteristics			
Mathematics achievement by fraction pre-test, m(SD)	10.31 (4.73)	9.81 (4.69)	8.03 (2.70)
General cognitive ability by BEFKI, m(SD)	7.94 (3.41)	7.25 (3.23)	7.49 (2.72)
Turkish language proficiency by C-Test, m(SD)		23.95 (13.17)	25.97 (13.07)
German language proficiency by C-Test, m(SD)	35.27 (9.17)	33.18 (8.34)	32.77 (5.52)
German academic language prof. by BiSpra-Test, m(SD)	19.06 (5.34)	17.03 (4.92)	17.20 (4.35)
Age by self-report, m (SD)	12.76 (0.70)	12.79 (0.78)	12.77 (0.65)

Table 1: Descriptive data for the full sample, the bilingual subsample, and the sample of this study

Methods of data analysis I: Coding the video corpus of the third intervention sessions

All utterances of the students (S1-S4) and teachers (T) were categorized turn-wise with respect to (a) speaker and starting / ending time of the utterance, and (b) language use (Turkish, German, mixed mode). Utterances with one switch from one language to the other were splitted and each part categorized. Utterances with borrowings or multiple code-switchings were coded as mixed mode. This categorization captures lexical aspects of language, while grammatical mixes are left out. The duration of the utterances is used for operationalizing the two use factors.

- *Percentages of talking time:* The operationalization of participation has to account for the fact that students in differently sized groups have different allotted talking times. Two students and a teacher theoretically have 30 min. of talking time each, while four students would only have 18 min. Hence, the allotted talking time is the theoretical talking time per group member with x group members, hence 90/x. The individual percentages of talking time is the share of actual talking time from the allotted talking time (which can be bigger than 100%). Students on average participated 90,45% of the allotted talking time. The averages in the groups are between 72% and 110%, and the individual participation varies between 20% and 210%.
- *Modes of language use:* The individual language use is operationalized as the share of Turkish, German and mixed modes from the total individual talking time. Table 2 shows the descriptive data for the modes of language use.

Methods of data analysis II: Hypotheses and model for the statistical data analysis

For statistically investigating the research question, the following hypotheses were validated by correlations: The learning gains of the bilingual intervention is connected to **H1** the percentage of talking time; **H2** the Turkish language use; **H3** the language proficiency in Turkish and German. For comparing the influences of factors, a regression analysis was conducted with the software R (https://cran.r-project.org/) for validating Hypothesis **H4:** Among the different factors, some exist which coincide significantly with the learning gains. If a Shapiro-Wilk test confirms the normal distribution, Pearson's Product-moment correlations r were determined, if not, Kendall's Tau τ was used. To rule out an effect of the groups on the investigated variables, the intra class correlation ICC was determined and tested for significance with boot-strapping.

Results

Descriptive findings for the modes of language use

Table 2 shows that both, teachers and students, participated in bilingual modes, i.e. in a mixed mode or in Turkish. On average, 52% of the overall talk time was Turkish or mixed (72% teachers, 30% students). Hence, there is a high degree of productive and receptive use of Turkish. Furthermore, a large percentage of the talk time is in mixed mode, so that both teachers and students seem to use every-day bilingual practices of code-switching and -mixing. However, individually, there are substantial differences in the language use. The group averages between teachers and students also vary strongly. This suggests that individual preferences of language use might in part be a result of group-specific practices of activating multiple languages. Nevertheless, in a teaching intervention in

which teachers consequently invest in the use of Turkish and mixed language, these numbers show that students can nevertheless be engaged in bilingual learning processes, compensating the low prestige of Turkish and the previous monolingual education.

	German mode	Mixed mode	Turkish mode
Teachers' average use of languages	27.5%	34.6%	37.4%
Students' average language use (all groups)	68.9%	13.6%	16.2%
Teachers' span of language use (min. – max. of the groups)	9.2% – 53.5%	15.7% – 56.4%	12.7% – 72.0%
Students' span of group average (min. –max. of the groups)	51.3% – 85.2%	4.9% – 26.5%	2.5% – 36.1%
Students' span of language use (min. – max. of all students)	16.1% – 96.8%	0% – 32.3%	1.5% – 56.1%

Table 2: Distribution of modes of language use for teachers and students (n=37 students)

Findings of influences of different factors

For investigating Hypotheses **H1–H3**, correlations were determined between the learning gains (difference between pre-test and follow-up-test) and the potential factors: The correlation with the German language proficiency is $\tau = 0.38$, with the Turkish and mixed modes in language use it is $\tau = 0.32$, these are two relatively high correlations. For the language use of only Turkish modes, the correlation is low with $\tau = 0.14$. No correlation exists with the percentage of individual talking time where $\tau = -0.03$. Thus, the hypothesis on relevance of active participation must be refuted.

To investigate the joint effects of the different factors on the learning gains (H4), a regression analysis with a stepwise model selection was performed (Table 3). As the learning gains of the small groups provide a non-significant ICC-value of 0.29 ($p > .05$), a multiple linear regression model is adequate.

	Regression coefficient b	Standard error (b)	Standardized regression coefficient
Model 1: All variables ($R^2 = 0.35$, R^2(korr.) = 0.14, $F(7,22) = 1.68$, $p > .05$)			
Intercept	–9.45	6.2	
German language proficiency (C-Test)	0.32	0.17	0.40
Fluid intelligence (Befki)	–0.0007	0.33	–0.0004
German academic language proficiency (BiSpra)	–0.05	0.26	–0.05
Turkish language proficiency (C-Test)	0.034	0.09	0.10
Socio-economic Status (Book index)	0.79	0.82	0.20
Use of Turkish and mixed mode	5.25	4.88	0.23
Percentages of talking time	–0.91	1.91	–0.092
Model 2: After systematic model reduction ($R^2 = 0.35$, R^2(korr.) = 0.30, $F(2,30) = 7.973$, $p < .01$)			
Intercept	–9.90 *	4.17	
German language proficiency (C-Test)	0.34 *	0.13	0.41
Use of Turkish and mixed mode	6.90	3.64	0.30
Model 3: Only German language proficiency as variable ($R^2 = 0.27$, R^2(korr.) = 0.25, $F(1,31) = 11.39$, $p < .01$)			
Intercept	–10.63 *	4.32	
Proficiency in German	0.44 **	0.13	0.52
Model 4: Only Turkish and mixed modes as variable ($R^2 = 0.20$, R^2(korr.) = 0.18, $F(1,31) = 7.873$, $p < .01$)			
Intercept	0.28	1.45	
Use of Turkish and mixed mode	10.33**	3.68	0.45

Table 3: Results of the regression analysis with stepwise model selection

Model 1 with all variables, while being complete, is not significant. A stepwise model selection results in a significant Model 2 ($F(2,30) = 7.973$, $p < .01$), which includes German language proficiency as significant factor for learning gains ($p < .05$). In comparison, Model 3 and 4 are models with single variables, namely German language proficiency and the use of Turkish and mixed mode, respectively. Overall, Model 2 has the best model accuracy with R^2(korr)=0.30. This model shows that a higher German language proficiency leads to higher learning gains: One additional point in the C-test leads to higher learning gains of 0.34. Also, the use of Turkish and mixed language is a relevant factor: 10% more use of Turkish and mixed language leads to 0.69 more points in the learning gains.

In sum, the learning gains in the bilingual teaching intervention coincide with the German language proficiency, but not the Turkish language proficiency or the German academic register. This student characteristic is combined with the use factor 'use of Turkish and mixed mode', which also shows a strong connection to learning gains.

Summary and discussion

This study contributes in the following ways to the research discourse on multilingual mathematics learning:

- Within usual language policies of monolingualism, the percentage of the mixed-language mode used by teachers and students is remarkable (Norén, 2015). By implementing certain principles for activating multiple languages, multilingual students can be fostered to activate their multiple languages in mathematical teaching learning situations, despite a language context which devalues the immigrant language Turkish.
- The finding that the share of Turkish and mixed language use in students' utterances best explains the learning gains in the bilingual teaching intervention (together with German language proficiency) is a quantitative evidence for many qualitative results which show how multilinguality can be a resource in learning processes (Planas, 2014; Norén, 2015).
- The students' percentage of individual talking time is not correlated to the learning gains. This confirms skepticism on too simple conceptualizations of active participation as talking time.
- In light of studies illustrating how conceptual tasks involving problem solving are especially accessible to multilingual students by means of certain discursive practices like discussing (e.g. Dominguez, 2011), the finding that students' German language proficiency significantly coincides with the growth of conceptual understandings may hint at a more complex relation between conceptual tasks and their utilization in discursive practices, and the languages used.

Interestingly, not the share of Turkish from an individual student's talk time, but the share of Turkish and mixed mode *together* have the second strongest influence on the long term achievement (Table 3). This is in line with Auer (2011) who identifies the mixed mode as the norm for Turkish-German multilinguals, and not the "pure" use of Turkish. This suggests that in bilingual classrooms the multilingual register and mixed mode are central pillars of the classroom discourse. Furthermore, it may suggest that a mixed mode allows deeper conceptual understanding (Wagner et al., 2018). Hence, in spite of its methodological limitations, this study confirms research which hints at the relevance of activating multiple languages in learning processes.

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