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CONTENT- AND LANGUAGE-INTEGRATED LEARNING: A FIELD EXPERIMENT FOR THE TOPIC OF PERCENTAGES

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Supporting language learners requires content- and language-integrated instructional approaches to coordinate conceptual learning trajectories with systematically structured language learning opportunities, so-called macro-scaffolding approaches. This paper provides empirical evidence for their effectiveness under field conditions in regular mathematics classrooms. For this purpose, a field experiment was conducted with n = 108 students based on a macro-scaffolding intervention for learning percentages. The ANCOVA shows that after 15 sessions of intervention, the intervention group significantly outperformed the control group (with comparable pre-knowledge) and medium effect sizes. This shows that teachers can foster language learners' conceptual understanding when supporting their learning by necessary language means.

BACKGROUND: FOSTERING LANGUAGE LEARNERS BY CONTENT- AND LANGUAGE-INTEGRATED APPROACHES

Academic language proficiency in the language of teaching and testing has repeatedly been shown to influence achievement in mathematics (see Barwell et al. 2016 for overviews). As a consequence, current design research activities have been focusing on developing and investigating content- and language-integrated instructional approaches for supporting students with low language proficiency (Gibbons 2002; Moschkovich 2013). In this paper, we contribute to these efforts by developing an instructional approach based on the design principle of macro-scaffolding (Gibbons 2002; Smit et al. 2013). The main idea of macro-scaffolding is to coordinate a conceptual learning trajectory with well-structured language learning opportunities in lexical and discursive dimensions. Although the general structure of language trajectories from students' everyday resources to academic registers and formal technical registers has been well described, its topic-specific realization for different mathematical topics is still an urgent need of research as the general lines do not sufficiently guide teaching practices (Smit et al. 2013).

Previous research has especially shown the high relevance of the discourse practice of explaining meanings of the mathematical concepts in view (Moschkovich 2013; Prediger & Wessel 2013). For this, macro-scaffolding approaches can be supported by the design principle of relating registers and representations, according to which the graphical and symbolic representations should be systematically related to the different verbal registers (the everyday registers, the academic school register, and the technical register) forward and backward in order to achieve a deep and well-connected conceptual understanding (Prediger & Wessel 2013). As some first empirical findings exist on the effects of topic-specific realizations of these instructional approaches and design principles (Gibbons 2002; Smit et al. 2013; Prediger & Wessel 2013; and others), further research can widen the approach to other mathematical topics and especially provide a wider base for quantitative empirical evidence for their efficacy. Since many of the existing studies on content- and language-integrated learning in mathematics education have taken place in laboratory small-group settings, it is time for the next step of research: investigating the functioning and effectiveness in whole-class settings with regular teachers in field experiments, as requested by Burkhardt and Schoenfeld (2013). That is why the current study continues the research on a content- and language-integrated macro-scaffolding intervention on percentages which has so far only been investigated qualitatively in laboratory conditions (Pöhler & Prediger 2015). The current step comprises a quasi-experimental field experiment in three classrooms with regular teachers and matching control students from other classes.

REALIZING MACRO-SCAFFOLDING FOR PERCENTAGES

In order to foster the conceptual understanding of students with diverse language backgrounds, an intervention was designed in several iterative design research cycles (described in detail in Pöhler & Prediger 2015). Based on general literature on students' difficulties with and teaching approaches for percentages (Parker & Leinhardt 1995), the intervention follows the design principles of macro-scaffolding and relating registers and representations. It coordinates on six levels a conceptual learning trajectory towards conceptual understanding and flexible use of percentages with well-structured language opportunities in a lexical learning trajectory (see Fig. 1).

The intended *conceptual learning trajectory* towards percentages (see Fig. 1) was adapted from previous design research on percentages in the context of Realistic Mathematics Education (van den Heuvel-Panhuizen 2003). It starts with students' everyday experiences and proceeds to constructing meaning for percentages. Students' informal strategies for determining rates, amounts, and bases are then elicited and later elaborated into calculation strategies for standard problem types. The conceptual learning trajectory finally aims at the ability to also flexibly use learned concepts and strategies in more complex and non-familiar situations.

The intended *lexical learning trajectory* (see Fig. 1) sequences the discourse practices and language means required for the conceptual learning processes. It starts from students' everyday resources by discussing intuitive ideas, establishes the discourse practice of explaining meanings and supports it using the *basic meaning-related vocabulary* for rates, amounts, and bases (e.g., old price, new price, rate to be paid), and then introduces formal vocabulary (base, amount, rate) and relates it to the basic meaning-related vocabulary for reporting and justifying formal procedures. Finally, the vocabulary is widened to the so-called extended reading vocabulary necessary to crack more complex percentage problems in non-familiar contexts.

	Conceptual learning trajectory towards mathematical concepts	Lexical learning trajectory for different discourse practices
Level 1	Constructing meaning for percents by representing and estimating rates	Intuitive use of *students' everyday resources* for discussing first ideas in percent bar
Level 2	Developing informal strategies for determining rates, amounts, later bases	Establish *basic meaning-related vocabulary* for explaining meanings
Level 3	Calculating amounts, rates, and bases	Introduce *formal vocabulary* in the technical register
Level 4	Widening to other problem types: change and comparison	Enrich the *basic meaning-related vocabulary* to more complex problem types
Level 5	Identifying problem types of (also non-)standard problems	Explicit use and training of formal and basic meaning-related vocabulary
Level 6	Cracking more complex context problems flexibly (non-familiar contexts)	Introduce extended reading vocabulary for non-familiar contexts

Fig. 1 Dual learning trajectories towards percentages

Both trajectories are mediated by a structure-based scaffold, the percent bar (van den Heuvel-Panhuizen 2003). The function of the percent bar changes on the levels of the dual learning trajectory, first functioning as a model *for* problem situations in the contexts of download bars and shopping, then as a model *of* the abstract mathematical concepts of percentages. Later, it serves as a strategic scaffolding tool for mathematizing complex word problems.

A sequence of 21 instructional tasks was developed for realizing the intended dual learning trajectory. Two exemplary tasks (in Fig. 2) illustrate how conceptual and lexical aspects are intertwined and how the percent bar can serve as a mediator. Students not only solve percent items, but are often encouraged to verbalize their structure. The vocabulary offered for these discussions is always bound to the percent bar, which allows students to relate the vocabulary to its meaning.

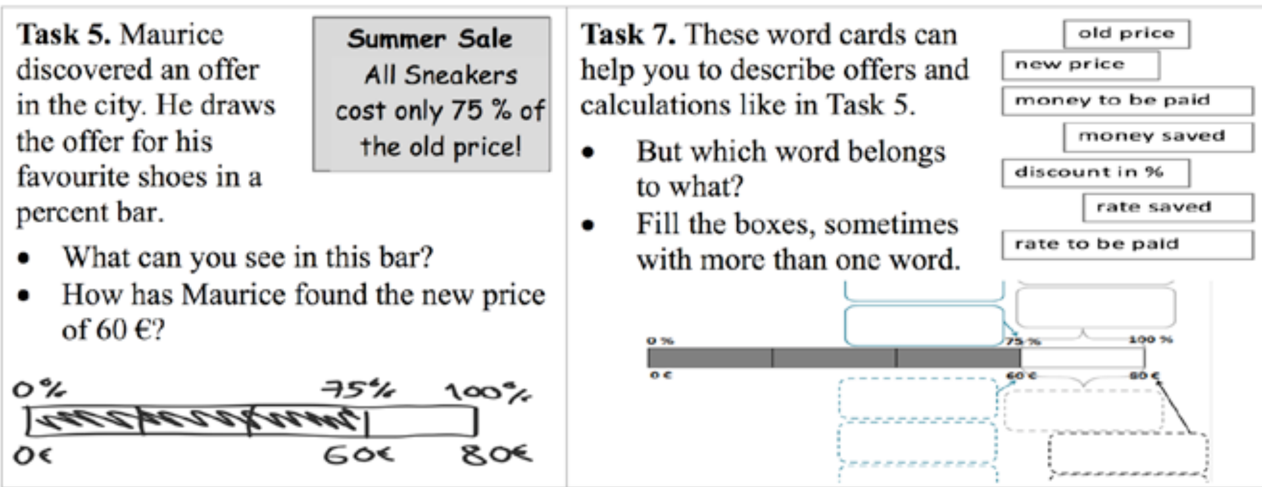


Fig. 2 Tasks exemplifying the intertwinement of conceptual and language aspects

The functional use of these successive vocabularies for the different discourse practices (explaining meanings, reporting strategies, justifying strategies) is scaffolded by language frames, word banks, and repeated teacher prompts initiating students' rich discursive practices. As the previous qualitative analysis of small-group teaching has reconstructed challenges for teachers to adaptively provide micro-scaffolding, a field experiment is required to test how regular math teachers can meet these challenges.

RESEARCH QUESTIONS

Previous design research case studies have qualitatively shown that the designed intervention on percentages was beneficial for low-achieving students with limited academic language proficiency in small-group settings (Pöhler & Prediger 2015). In order to also extend the scope to regular teachers and to provide quantitative empirical evidence for the effectiveness, the current study tested the effects of the intervention in a field experiment in whole-class settings with two research questions:

Q1. What are the learning outcomes of the intervention group compared to the control group?

Q2. What are the learning outcomes of intervention and control group for the three problem types (Find the base, find the amount, and find the base after reduction)?

METHODS OF THE FIELD EXPERIMENT

Research design. The research was conducted as a quasi-experimental field experiment with a pre- and post-test design with seventh graders in urban schools in whole-class settings, taught by their regular teachers, all of whom had been sensitized to language issues in classrooms by professional development.

Intervention forms. The three intervention classes were taught in approximately 15 sessions of 45 minutes each by means of the described macro-scaffolding intervention program on introducing percentages with the dual learning trajectory. The control classes were taught according to the traditional program for percentages, which included the same mathematical content but did not follow the lexical and conceptual learning trajectory and the principle of relating registers and representations.

Measures for control variables. For achieving comparability between intervention and control group, the following control variables were taken into account:

(1) German *language proficiency* was assessed using a C-Test, offering economical and highly reliable measures, with Cronbach's $\alpha = .774$ ($N = 1,122$),

(2) *Mathematical pre-knowledge* that is relevant for learning percentages (fractions, parts of whole, bar representations, etc.), measured before the intervention by a standardized test (from Prediger & Wessel 2013) with Cronbach's $\alpha = .83$ (28 items, $N = 1120$), and

(3) General cognitive ability was assessed using BEFKI, with a focus on figural dimensions of *fluid intelligence*, with Cronbach's $\alpha = .76$ ($N = 1122$).

Measure for the learning outcome. The learning outcomes of the interventions were assessed using a standardized test on percentages that was optimized to assess conceptual understanding and flexible use of percentages. It consists of open items of the problem types “Find the amount,” “Find the base,” and “Find the base after reduction.” For each problem type, items varied in three formats: “pure format,” “text format,” and “visual format,” with percent bar representations (examples in Table 1).

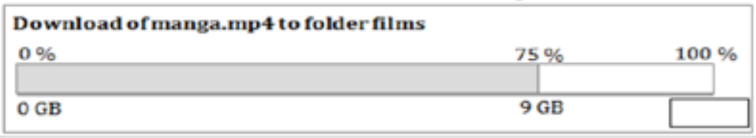
Example items for problem type “Find the base”	
Pure format	5 % are 250 €. Find the base.
Visual format	What is unknown here? Find the missing value. 
Text format	Potatoes consist of 75 % water. How much water (in g) is contained in 1000 g potatoes?
Example item for problem type “Find the amount”	
…	
Text format	When buying a new kitchen, Family Mays receives a discount of 250 €, that was 5 % of the regular price. What is the normal price of the kitchen?
Example item for problem type “Find the base after reduction”	
…	
Text format	Mrs. Schmidt pays 30 € for a dress in the summer sale. The dress was reduced by 40 %. How much did the dress cost before?

Table 1 Items in the percent test in different problem formats

Sample. In order to achieve comparability in the quasi-experimental field experiment, each student of the intervention group was matched to a student from the control classes with respect to the control variables (see Table 2). In the variance tests, no significant differences appeared between the intervention group (n = 54) and the control group (n = 54) for the three control variables: language proficiency, mathematical pre-knowledge, and fluid intelligence (with $p > .05$ in the t-tests for all three variables).

	Language proficiency (max. 60) m (SD)	**Mathematical pre-knowledge (max. 19) m (SD)**	**Fluid intelligence (max. 16) m (SD)**	**Socio-eco nomic status (max. 5) m (SD)**	**Age in years m (SD)**
Intervention group (n = 54)	41.17 (6.95)	11.89 (4.96)	9.11 (3.02)	2.69 (1.12)	12.53 (0.74)
Control group (n = 54)	40.89 (7.2)	11.61 (4.28)	9.13 (3.82)	3.24 (1.12)	12.57 (0.66)

Table 2 Description of the comparable subsamples

Methods for data analysis. As the pre-test measured a wider repertoire of pre-knowledge than the post-test did, with its specific focus on percentages, the analysis of the effects of intervention were calculated using a covariation analysis (ANCOVA). This allows comparison of the differences in the learning outcomes of the intervention and control groups by taking into account the control variables. The ANCOVA was conducted for the complete percent test as well as the subscales of different problem types (Find amount, find base, find base after reduction; see Table 1). While the qualitative data analysis of the videotaped teaching-learning processes will be documented in further publications, this paper focuses on the quantitative results.

EMPIRICAL RESULTS AND INTERPRETATION

Research question Q1 asks for differences in the learning outcomes between the intervention group (who followed the content- and language-integrated intervention on percentages) and the control group (who followed a traditional percentage course). The descriptive data for this research question presented in the second column of Table 3 shows that the whole sample achieved an average score of 36.7. The intervention and control group (which were comparable with respect to the relevant control variables of language proficiency, mathematical pre-knowledge, and fluid intelligence) performed differently in the percent test after the intervention: The intervention group achieved an average score of 45.4, whereas the control group only achieved 28.0 (with similar standard deviations).

	Complete percent test (max. 100) m (SD)	**Subscale Type "Find amount" (max. 33.3) m (SD)**	**Subscale Type "Find base" (max. 33.3) m (SD)**	**Subscale Type "Find base after reduction" (max. 27.8) m (SD)**
Whole sample	36.7 (25.7)	14.2 (8.9)	15.0 (11.0)	6.1 (9.1)
Intervention group (*n* = 54)	45.4 (26.4)	15.8 (8.5)	18.4 (10.0)	9.7 (10.2)
Control group (*n* = 54)	28.0 (22.3)	12.6 (9.0)	11.5 (10.8)	2.5 (5.8)

Table 3 Group differences in the learning outcomes

The covariation analysis for the complete percent test (reported in Table 4) shows the anticipated result that mathematical pre-knowledge is a significant predictor for learning outcomes ($p < 0.01$). When controlling for the language proficiency, mathematical pre-knowledge, and fluid intelligence, the independent variable of belonging to either the intervention group or the control group shows a significant difference between the two groups (with $F(4,103) = 14.7497$, $p < 0.0000$). The effect size is captured by a partial eta squared of $\eta^2 = 0.141$, which is considered a medium effect.

Variables	Regression coefficient	Standard error	p-value	Partial η^2 (proportion of variance in percent test explained by variable)
Intercept	-1.454	2.212	0.512	0.004
Language proficiency	0.096	0.057	0.097	0.027
Mathematical pre-knowledge	0.343	0.097	0.001	0.109
Fluid intelligence	0.177	0.126	0.165	0.019
Intervention/control group	-3.018	0.733	0.000	0.141
$R^2 = 0.364$, $R^2_{\text{Adj}} = 0.34$, $F\,(4,103) = 14.7497$, $p < 0.0000$				

Table 4 Results of the ANCOVA for the complete percent test

Research question Q2 asks for differences between both groups for the subscales of different problem types (Find the base, find the amount, and find the base after reduction). As the different means in Table 3 (columns 3 to 5) show, the intervention group outperforms the control group in all subscales. The differences are smallest for the most elementary problem type, "find the amount," for which the intervention group reached a score of 15.8 and the control group of 12.6 (a difference of 3.2). For the inverse problem type, "find the base," the scores of 18.4 and 11.5 differ by 6.9 points. For the most complex problem type, "find base after reduction," which requires two-step thinking, the scores of 9.7 and 2.5 differ by 7.2 points. The ANCOVAs for all three subscales provide evidence for significant group differences when controlling for language proficiency, fluid intelligence, and mathematical pre-knowledge:

$F_{\text{Find amount}}$ (4,103) = 9.0898, $p < 0.05$, $\eta^2 = 0.04$ (small effect size)
$F_{\text{Find base}}$ (4,103) = 10.6239, $p < 0.001$, $\eta^2 = 0.105$ (medium effect size)
$F_{\text{Base after red}}$ (4,103) = 9.5627, $p < 0.0001$, $\eta^2 = 0.187$ (large effect size).

To sum up, the group differences in problem types of different varying and familiarity might be interpreted as indicating that the percent is a fruitful strategic tool for mathematizing, especially for complex problem types (find base after reduction) and for avoiding over-generalizations. These interpretations are supported by previous qualitative analyses of small-group settings (Pöhler & Prediger 2015).

DISCUSSION

The larger design research project in which this field experiment is embedded aims at designing and investigating the functioning of content- and language-integrated approaches based on the design principles of macro-scaffolding and relating registers and representations. This research is specifically important in classes with diverse language backgrounds (Gibbons 2002; Smit et al. 2013; Prediger & Wessel 2013). Previous qualitative analysis of the intervention has shown the principal transferability of these approaches to mathematical topic percentages (Pöhler & Prediger 2015). However, it has also shown the high relevance of micro-scaffolding by teachers, so it has been an open question as to whether the intervention would also be effective under regular classroom conditions.

In this paper, we provided empirical evidence that the intervention has had better effects on students' conceptual understanding and flexible use of percentages than traditional courses. Many other studies have shown that such evidence is more difficult to provide under field conditions than under laboratory conditions (Burkhardt & Schoenfeld 2003): Whole-class settings with students' regular teachers have a higher complexity and typical constraints for implementing research-based designs. Nevertheless, the ANCOVA results in a significant difference with high effect sizes: Students who acquire conceptual understanding of percentages in a content- and language-integrated intervention based on principles of macro-scaffolding and relating registers outperform students learning in a traditional course with the same content. The comparability between intervention and control group was controlled for the control variables of language proficiency, mathematical pre-knowledge, and fluid intelligence. The detailed analysis of learning outcomes on different problem types provided insights into the specific strength for non-routine problems. However, further qualitative analysis of the classroom video data will be necessary to understand the chances and limits in more detail.

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