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How theories of language-responsive mathematics can inform teaching designs for vocational mathematics

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This paper gives an overview of an Erasmus+ project that aims at empirically identifying the potentials and challenges of language-responsive teaching designs for low-achieving students in vocational contexts by means of topic-specific design research. It delivers first insights into developing and experimenting with two teaching units (percentages and proportional reasoning) and summarizes the questions that come up when adapting design principles for language-responsive mathematics teaching for the teaching and learning of young adults in vocational education. The empirical investigations are carried out with young adult pre-apprentices in lower vocational education in Germany in the technical sector. These young adults are often low achievers in mathematics and often have only limited language proficiency in the language of instruction.

Keywords: Vocational education, language, percentages, scaffolding, design research.

Theoretical background for designing teaching-learning arrangements in vocational settings

Legitimization and justification for further developing mathematical literacy in vocational education to a certain degree, amongst others, lies in the utility of mathematics in the workplace. However, we can draw on empirical research gained in different vocational sectors showing that the workplace mathematical practices often differ from school mathematical practices (Noss, Hoyles, & Pozzi, 2000). With reference to Noss et al. (2000), LaCroix (2014) summarizes that

it is recognized that mathematics practices in the workplace are shaped by the immediate and practical requirements of workplace production; that is, getting particular tasks accomplished with ease and efficiency using resources at hand rather than the goals and norms of generality, formality, and internal consistency commonly associated with school mathematics. (LaCroix, 2014, p. 159)

These differences can serve as an important starting point for joint reflection in vocational mathematics classrooms so that the mathematics teaching and learning is meaningful for the students. When it comes to designing teaching and learning arrangements for mathematics in vocational education, a further important aspect, which can be perceived as a challenge as well as a resource, is the huge variety of vocational sectors in which students are accomplishing their vocational education and which lead to many differences in the way that students meet the mathematical demands, since the mathematical demands on the job are not only topic specific, but especially also vocation specific (for an overview of vocation-specific research see LaCroix, 2014, p. 159).

Many students are mathematically unprepared to face the demands of vocational education or vocational training (Hoyles, Noss, Kent, & Bakker, 2010). While mathematical literacy is important

for meeting these demands, PISA results for Germany show that 17.2 % of the middle school students cannot rely on sufficient mathematical competencies to continue education in an apprenticeship training position. As a consequence, many German students (mostly aged 16-22) continue schooling at vocational schools as pre-apprentices and enroll in classes to obtain a middle school degree.

Besides experiencing difficulties in test situations, students with low language proficiency experience difficulties in the learning situations themselves. This relates to the role of language as a learning medium in classrooms: Language in mathematics classrooms is at the same time a medium of knowledge transfer and discussion and a tool for thinking (*communicative* role of language vs. *epistemic* role of language, Pimm, 1987). Taking both roles of language into account, research in mathematics education repeatedly emphasizes the intertwining of language and mathematical thinking for all students, but especially for students still acquiring the language of instruction (e.g., Moschkovich, 2015). As a consequence, current design research studies in primary and secondary mathematics education focus on developing and investigating content and language integrated instructional approaches for fostering students with low language proficiency (e.g. Prediger & Wessel, 2013). Theoretical and empirical approaches are pursued to postulate design principles for intertwining conceptual and language learning trajectories, while language unfolds into the different levels e.g. the lexical and discursive level of language (Pöhler & Prediger, 2015; Wessel & Erath, 2018).

With respect to vocational education, the importance of language proficiency for successfully meeting the demands of the workplace is also well recognized, especially from the perspective of general didactics and more general vocational pedagogy (compared to vocational *mathematics* education research) (Ziegler, 2016). Specific vocational language demands - such as the discursive demand of counseling situations in communication with customers - are identified. On the lexical level, challenges are often traced back to the specific vocabulary relevant and needed in a specific profession or vocational sector.

However, an analysis of language demands only 'on the job' is too restrictive and shortsighted, because students are already confronted with vocation-specific language demands in workplace-related mathematics teaching and learning situations. In mathematical learning processes, language plays an important role in an epistemic role for developing students' understanding of mathematical concepts. Thus, in intended learning trajectories in which linguistic and mathematical learning trajectories are intertwined also the vocation-specific language demands have to be taken into account.

When aiming at unfolding the relation of language, especially vocation-specific language and corresponding language demands, and mathematics embedded in workplace settings, one recognizes and has to admit an enormous complexity along with a lack of theoretical approaches to acknowledge this complexity. Thus, this research wants to contribute to theorizing the complex relation with respect to topic-specific vocabulary and discourse practices as learning opportunities for deeper mathematics learning.

Research and task design gap

Empirical research on language-responsive teaching and learning of mathematics for the primary and secondary school levels is still relatively young; however, important theoretical considerations by now are more than 30 years old (Pimm, 1987) and there is a constantly growing and consolidating theoretical foundation from mathematics education and linguistic theory to be drawn on in design research projects. At the same time, the practical realization of well-defined design principles in content and language integrated approaches is topic-specific (e.g. language for understanding *percentages* differs to a certain extent from language for *understanding functions*) and there is still a huge lack of research which aims at systematically specifying the topic-specific language demands for the different mathematical topics.

When it comes to vocational teaching and learning of mathematics, the aspect of language in vocational mathematics learning processes is at the moment not that much in focus as it is in primary and secondary mathematics education; however, aspects of language are implicitly touched due to the deep connection of language and the theoretical approaches (like webbing and boundary crossing) being pursued. Still, like language-responsive teaching designs are always topic-specific, recent insights into content and language integrated teaching can neither simply, nor entirely be transferred to vocational settings (just to mention age, previous experiences with mathematics in middle school, the often described very huge heterogeneity, the case of remedial learning, (mathematical) practices of and at the workplace, the many different vocational sectors etc. as a small selection of the changing surroundings that must be taken into account).

That is why there is an urgent need for empirical qualitative and quantitative research that carefully investigates the situative effects and potentials of language-responsive vocational mathematics teaching and learning. We hereby rely on the notion of language-responsiveness as mathematics teaching that accounts for and is sensitive to multiple languages (which, amongst others, can be conceptualized as different national languages, different language registers, or non-verbal semiotic means) in order to enhance deeper understanding of mathematics (sometimes different terms like “language-sensitive mathematics” or “content- and language integrated teaching” are used, see Wessel & Prediger, 2013 for further elaboration).

Research questions

For minimizing the above described design and research gap, in this paper vocational-specific resources and differences when extending the approach of language-responsive mathematics to vocational mathematics education are pursued. Thus, the paper aims at answering the following research question: Which differences can be identified when consolidated design principles for language-responsive mathematics teaching for middle school teaching are adapted to lower strands of vocational education?

Research context and methodological framework

The project “*Language for Mathematics in Vocational contexts*” is an Erasmus+ funded research project in which mathematics education researchers collaborate with teachers from vocational schools from Germany, the Netherlands, and Sweden. The team develops empirically consolidated

language-responsive mathematics teaching units for the mathematical fields ‘understanding percentages’, ‘proportional reasoning’, and ‘understanding diagrams and graphs’ for vocational education of pre-apprentices as well as professional development modules for mathematics teachers at vocational schools. For this paper, the focus will be on the classroom level. The developmental work on the classroom level concentrates on those strands of vocational education for young adults who are not yet in an apprenticeship training position, but aim at completion of a middle school degree. The mathematical foci were chosen because of their importance for the target group, and because the researchers already gained experiences with developing language-responsive teaching material for these topics in secondary school classrooms.

The young adults (16-22y) in the German part of the project often did not yet successfully develop the main mathematical concepts and are often not yet fully fluent in applying the main procedures which are in the fore of the middle school mathematics curriculum. Consequently, the teaching units take into account design principles for remedial learning. In addition to that, the young adults enrolled in these strands of vocational education also belong to the group of vulnerable students with respect to language proficiency.

The research is conducted in the methodological framework of topic-specific didactical design research (Prediger & Zwetzscher, 2013) in which the analysis of teaching-learning processes takes place in carefully designed teaching experiments. Design experiments are considered the methodological core of design research studies as they allow in-depth investigations of learning *processes* rather than only learning *outcomes* (Gravemeijer & Cobb 2006). They serve as means of data gathering for qualitative in-depth analyses of the young adults’ learning processes.

The design experiments are video-taped and conducted in small-group or partner design experiments as well as whole-class teaching experiments. The video data is analyzed qualitatively with well-proven language activation categories of our previous research which is combined with inductive development of categories. All whole-class teaching experiments are carefully planned in each national team of researchers and teachers, e.g. in the here reported German team of two mathematics education researchers and seven teachers from three partner vocational schools. Furthermore, the researchers draw on classroom observations and field notes from all whole-class teaching experiments and subsequent discussions on what works well and does not work well.

Throughout the project and for the different mathematical topics being investigated, specifying and structuring the learning trajectories differs due to the different disposability of previous research. In the first year (Sept. 2017 - Sept. 2018) and for the teaching unit ‘percentages’, the developmental work relies on a consolidated intertwining of conceptual and lexical-discursive learning opportunities (Pöhler & Prediger, 2015; Pöhler, 2018) for middle school teaching that is being adapted. The following results and conclusions for the raised research questions rely on the adaptation process of the teaching unit ‘percentages’ and draw on teachers’ and researchers’ observations and field notes from six vocational classes in which the adaptations of the teaching unit have been used in the academic school year 2017/18. The teaching unit was taught over 4-5 lessons of 90 min. each in each of the classes and video-data for at least one lesson per class was gathered.

First conclusions from adapting a language-responsive teaching unit

In order to understand the changes that have been identified as important when adapting a language-responsive teaching unit for vocational classes of a lower strand of vocational education, the next paragraph gives an overview of important design principles for language-responsive mathematics teaching and which have been realized in the teaching unit designed and empirically investigated by Pöhler (2018).

Design principles for language-responsive mathematics teaching and learning

Design principle “Macro-scaffolding by intertwining language and conceptual learning trajectories”. The general structure of intended language learning trajectories is well described in the principles of *macro-scaffolding*, namely from students’ everyday resources to academic and formal technical registers (Gibbons, 2002). For their developmental work, Pöhler and Prediger (2015) connect the level principle from *Realistic Mathematics Education* for conceptual learning trajectories with macro-scaffolding of language. According to the level principle, a hypothetical learning trajectory is to be sequenced over four levels of increasing deepness of understanding (from the situational level to the referential level, to the general level, to the formal level) (Gravemeijer, 1998).

Levels	Conceptual learning trajectory: Mathematical conceptions	Lexical learning trajectory through different vocabularies
Level 1: Informal thinking starting from students’ resources	Constructing meaning for percents by representing and estimating rates	Intuitive use of students’ resources in everyday register, no offer of new lexical means
Level 2: Informal strategies and meaning-related vocabulary	Developing informal strategies for determining rates, amounts and later bases	Establish basic meaning-related vocabulary in the academic school register for constructing meaning for rates, amounts, bases in context
Level 3: Procedures for standard problem types	Calculating amounts, rates and later bases	Introduce formal vocabulary in the technical register
Level 4: Extending the repertoire	Widening to other problem types: change and comparison	Enrich the basic meaning-related vocabulary to more complex problem types
Level 5: Identification of different problem types	Identifying problem types of (non-) standard problems (in diverse contexts)	Explicit use and training of formal and basic meaning-related vocabulary
Level 6: Flexible use of concepts and strategies	Cracking more complex context problems flexibly (in non-familiar contexts)	Introduce extended reading vocabulary for various non-familiar contexts

Figure 1: Combining conceptual and lexical learning trajectories – macro-scaffolding example for percentages (Pöhler & Prediger, 2015)

By intertwining the two dimensions of sequencing (conceptual dimension and lexical dimension), Pöhler and Prediger (2015) develop the dual learning trajectory towards understanding percentages depicted in Figure 1: The conceptual learning trajectory is sequenced in six steps starting from students’ resources in informal thinking to informal strategies, formal procedures and their flexible use. Each step requires other discourse practices and different vocabularies which are sequenced in the lexical learning trajectory (Fig. 1 on the right).

On the lexical learning trajectory, the teaching unit starts from the students’ individual language resources (level 1) and the basic meaning-related vocabulary. These lexical means from our vocabulary are especially important for explaining the meaning of concepts: meaning-related vocabulary grasps mathematical relations and meanings (e.g., *take away* for the meaning of subtraction). It usually belongs to the academic school register and should be introduced before

formal vocabulary (Wessel, 2015) (see level 3 where introduction of formal vocabulary begins). Empirical evidence has been given that this intertwinement can be effective for mathematics learning (Pöhler & Prediger, 2015).

For pursuing the research question “Which differences can be identified when consolidated design principles for language-responsive teaching for middle school teaching are adapted to lower strands of vocational education?”, the focus is put on the design principle *Macro-scaffolding by intertwining lexical and conceptual learning trajectories*. Figure 2 depicts the adapted combined learning trajectory for the teaching unit percentages for vocational education. Reasons for how the adaptations have been made are (amongst others) explained in the following.

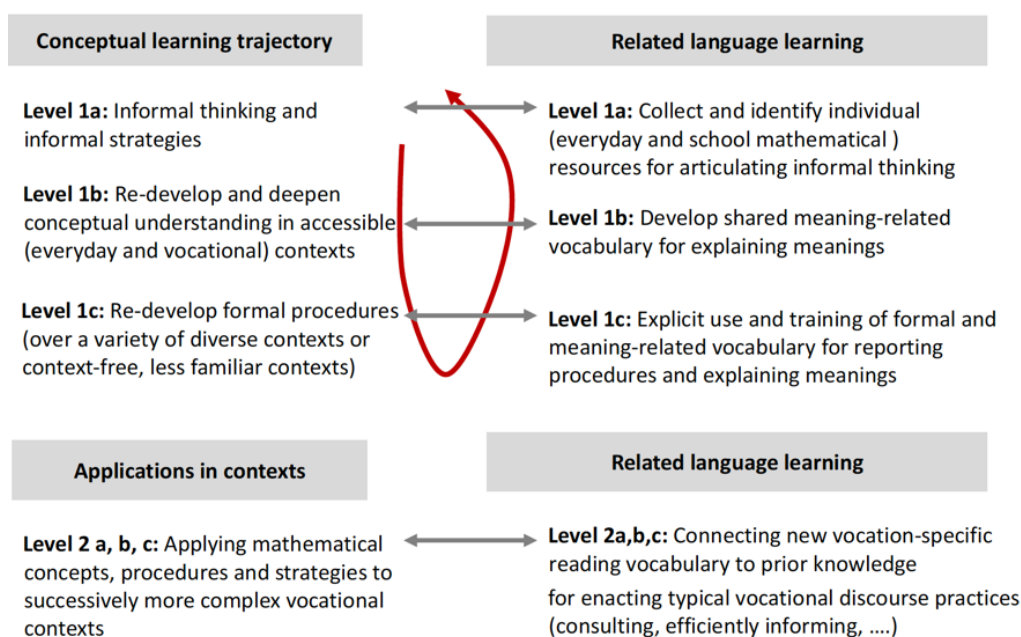


Figure 2: Adapted combined conceptual and lexical learning trajectory for workplace-related teaching and learning of percentages

In the case of lower vocational strands in which the research is conducted, teachers only have little teaching time for remedial learning of percentages and the young adults have prior knowledge from their middle school teaching. That is why the learning trajectory has been condensed to two levels in each dimension. The transition to workplace-related, vocational contexts is implemented in level 2, which means that on purpose the re-activation of understanding percentages happens in familiar, everyday contexts (shopping, downloads). Consistently, the vocation-specific language is accounted for on level 2 in the language learning trajectory.

Insights from teaching experiments with the adapted teaching unit and conclusions

When conducting and reflecting on the teaching experiments with the adapted percentages tasks, two main insights have been gained with respect to the design principle under investigation and task design.

Firstly, the young adults already know percentages, to some extent some calculation procedures, and percent-specific language like the formal (more technical) vocabulary, so that they can recall on

this knowledge. However, we experience many instances in which procedures are carried out without understanding, as well as instances in which the formal vocabulary is not filled with adequate meaning. As a consequence, the formal vocabulary can be used as starting point for raising students' awareness for the need to developing deeper conceptual understanding. Working on conceptual understanding of percentages builds on meaning-related vocabulary and reflecting on the different registers in carefully designed teaching activities. In a concrete task design, the vocational discursive demand of counseling was thus taken as a resource to initiate meta-reflections on language: In a language-responsive activity students are asked to translate a dialogue with customers given in very technical language into a more natural meaning-related form. We thus conclude that a further analysis of the authentic, vocation-specific discursive demands is promising, because they serve as meaningful situations to be drawn on in language-responsive teaching of workplace-related mathematics.

Secondly, it turned out that the levels 1a to 1c of the adapted learning trajectory in practical teaching are not realized as levels but resulted rather in a back- and forth between the three levels, both in the conceptual and in the language dimension. We hypothesize that this is also due to prior knowledge of percentages that the young adults have already acquired in their middle school mathematics. As a consequence, the question must be raised to which extent the design principle of sequenced learning trajectories is fruitful in those strands of vocational remedial education.

Outlook

The above empirical insights led to the question which further design principles are relevant to make language-responsive teaching work fruitfully at vocational level. At the moment, the project team is working on this question and implements for example the principle "Accounting for high heterogeneity without neglecting rich communication". Thus, we account for the so far often referred to different conditions of lower vocational education compared to general middle schooling. In a next step, further research is conducted to analyze the hypotheses and raised questions concerning the implemented design principles as well as to identify the potentials and effects of language-responsive teaching in vocational contexts.

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