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Linguistic features of word problems that cause difficulties for learners across the curriculum: A literature review

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Word problems can be challenging for learners of all ages on different levels. In this paper, specific linguistic requirements and features of word problems contributing to the difficulties for learners will be discussed. For this purpose, first results of a literature review are presented. The literature was analysed according to the model of genre features (Rezat & Rezat, 2017) as a theoretical framework. In the course of the literature review, a system of categories was developed to differentiate the linguistic features addressed in the respective studies. The studies that were assigned to the feature of linguistic complexity are discussed in detail with the aim of identifying specific linguistic features of word problems that cause difficulties for learners. The curricular context and the mathematical content of the studies will also be discussed.

Keywords: Word problems, literature reviews, syntax, linguistic complexity.

Introduction

In the sense of the spiral curriculum, applications are regarded as a topic that should be treated in an appropriate way at different grade levels (Müller & Wittmann, 1984, p. 4193). Word problems are a central type of task of teaching applications of mathematics at all ages. Therefore, they can be seen as a specific genre of mathematics education. A genre is defined as a “pattern of cultural-social interaction in a particular context” (Rezat & Rezat, 2017, p. 4193). In general, language and language use made for didactic purposes is an issue in every subject (Schlepppegrell, 2004). Schlepppegrell (2004, p. 82) points out that “[s]chool is a culture with its own expectations for particular ways of using language. [Therefore,] students need to learn about genres of schooling and the purpose for which they are useful.”

Research has shown that learners at all ages have difficulties with word problems. Daroczy et al. (2015) point out that those features of word problems, which generate difficulties for learners can be at mathematical, factual-semantic, and linguistic-syntactic levels. However, it is unclear which specific challenges these are, in which grades and for which mathematical contents these are relevant, how they develop within the curriculum, and whether difficulties in one mathematical context can also be transferred to other mathematical content areas. Furthermore, Daroczy et al. (2015) highlight that a comparison of previous research results related to word problems is usually not possible. Verschaffel et al. (2020) reinforce this statement. They point out that various (international) research projects on word problems focus on different perspectives about the research topic. Therefore, there is a need for a systematic analysis of pre-existing research results that addresses the requirements and the characteristics of word problems that generate difficulties for learners from a curricular perspective. The systematic analysis of the research findings presented in this paper will focus on the results related to linguistic features of word problems and how they impose difficulties on learners. The following research questions will be addressed:

Q.1: What are linguistic features of word problems that cause difficulties for learners across primary- and secondary¹ level curriculum?

Q.1.1: What specific linguistic features of word problems have been investigated in previous research?

Q.1.2: Which of these specific linguistic features of word problems affect the learners' solution processes and quality of solutions?

Theoretical framework of the literature review

In order to be able to systematically represent the research results with regard to linguistic task features, the *model of genre features* (Rezat & Rezat, 2017) was used as an instrument. It is grounded in the pragmatic linguistic approach. In the model, a genre is described as a connection between the *type of act* and the *text type*. The authors describe the relationship of both main categories in the model as follows: "The type of act directs the expectation of the text type while features of the text type, especially the formulation patterns, indicate the type of act." (p. 4196). The main category *type of act* was defined based on Halliday's (1985) modelling of the situation of the text, integrating the three social functions of language: field, tenor and mode. Structural features (*structure of the text*) and linguistic features (*language features*) are assigned to the main category *text type*. The main category *text type* is used as a framework in the literature review to systematically identify studies in which linguistic and structural features of word problems are discussed. On basis of the systematic literature review, the genre-specific language features of word problems are determined. Language features that cause difficulties for learners are defined as features that impair learners' solution processes and/or quality of solutions.

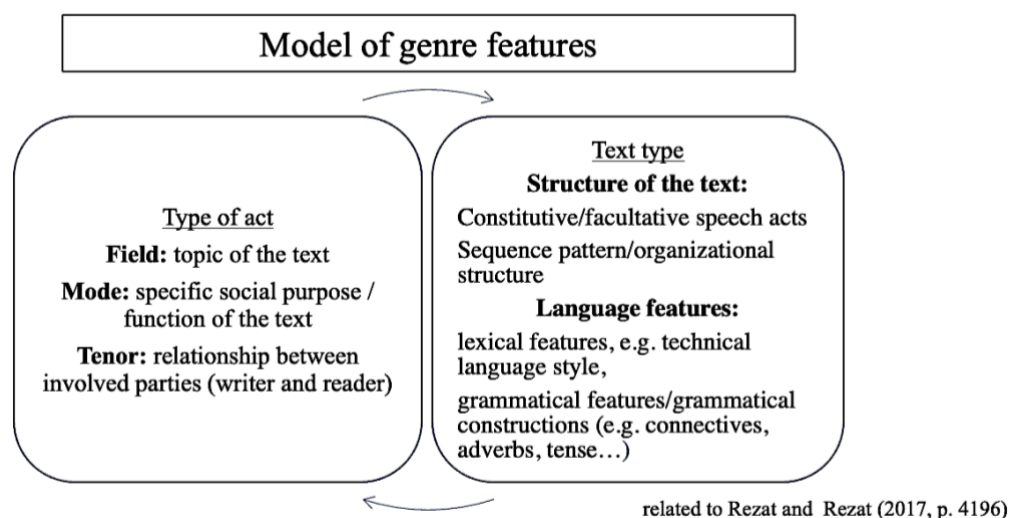


Figure 1: model of genre features

¹ The differentiation between primary and secondary school is based on the international standard. Primary level is understood up to and including grade 6.

Methodology of the literature review

In this section, the procedure of the literature review, which was conducted systematically is presented. Based on a specific literature search via the online literature database ERIC (<https://eric.ed.gov>)² a corpus consisting of 354 scientific articles (peer reviewed) was identified. The identified corpus was analysed based on qualitative content analysis according to Mayring (2015). The main category *text type* of the *model of genre features* with the subcategories *structure of the text* and *language features* was used to systematise the results. The category *language features*, which is the focus of this paper, comprises studies that analyse specific *lexical or grammatical features* of a text. Considering these criteria, a review of scholarly publications was conducted to determine the extent to which structural and language features, especially the *lexical or grammatical features* of word problems were addressed. For the review of the whole corpus, exclusion rules were also set and used for the analysis. This led to the removal of contributions that are not relevant in connection with the research questions. Consequently, papers that discuss the performance of learners with word problems (presentation in first and second language) and do not discuss the influence of linguistic features of the task, that analyse teachers' behaviour with word problems, and those that present interventions of teaching methods were excluded. Furthermore, studies that focus on interaction processes between learners, studies that address word problems from preschool or adult education and studies that address language/mathematical difficulties of learners with disabilities are excluded. The remaining corpus was analysed using the deductively developed categories and, if necessary, was extended by inductively formed categories.

Results

By means of the procedure described above, a total of 20 scientific publications were identified in which specific *language* and *structural genre features* of word problems in different grade levels are addressed. Of these 20 papers, 14 papers were assigned to the subcategory *language features*. The following section presents the results related to research question 1.1, followed by the results related to research question 1.2.

Results of the literature review in terms of investigated language features

The categories of language features provided in the model of genre features (Rezat & Rezat, 2017) were too general to allow for a differentiated view of the specific linguistic features of word problems that have been addressed in previous research and how they impose difficulties on learners. Therefore, the 14 scientific publications assigned to the category language features were inductively classified into different subcategories in order to be able to differentiate the particular language features that were investigated in these studies. In total, 5 subcategories could be developed.

Table 1 shows the subcategories describing the *language features* addressed in the respective studies and their definitions as well as the grade levels, in which the language features were investigated.

² The following search term was used: (“Word problems” OR “Story problems”) AND (language OR syntax OR “text structure” OR “word order” OR lexicology OR “visual aids” OR “illustrations”)

Table 1: Inductively formed category system of the literature review

Inductive category	Definition of the category: Studies, ...	Number of studies	Grade
(In-) consistency of language	... in which the influence of (in-)consistent language in the task is addressed in relation to the solution or comprehension processes.	5	1, 2, 3, 4 and 5
Personal pronoun	... in which the influence of personal pronouns in the task is discussed in relation to the solution or comprehension processes.	2	1 and 4
Vocabulary	... in which the influence of the vocabulary of the word problem and the vocabulary of the learners are addressed in relation to the solution or comprehension processes.	3	1, 7 and 8
Linguistic complexity	... in which the influence of lexical and/or grammatical features and/or features of the information structure related to the solution or comprehension processes are addressed.	5	1, 2, 5, 7, 8, 9 and 10
Deictics	... in which the influence of deictic expressions in the task is discussed in relation to the solution or comprehension processes.	1	10

The category syntactic/linguistic complexity comprises studies in which a combination of several individual linguistic features was varied at once in order to determine the influence of this variation on students' solution processes and/or quality of solutions. Since this feature is linguistically conceptualised differently, an overview of which linguistic features were (systematically) varied in the related studies is given to discuss this category in more detail. The linguistic modifications of word problems that were made in the study of Abedi and Lord (2001, p. 221) included: Unknown or rare words were changed, passive verb forms were transformed to active ones, long nominals were shortened, conditions were replaced by separate sentences, or the order of conditional and main clauses was changed, abstract or impersonal utterances were made more specific, complex questions were simplified by using simple question words. Leiss et al. (2019) increased the linguistic challenges of word problems by modifying four features: vocabulary, use of connectives, complexity of grammatical structures and information structure. In another study, a higher linguistic complexity was created by combining three original sentences of the tasks into one complex sentence (Muth, 1984). The following linguistic characteristics were varied individually in the study of Walkington et al. (2019): number of sentences, word hypernymy, pronouns, word concreteness, consistency of sentences, the topic of the task. Ambrose and Molina (2014) see linguistic complexity at the level of syntax and vocabulary.

Summarising this overview, it becomes apparent that on the one hand there are studies that focus on individual linguistic features of word problems, while on the other hand some studies focus on a combination of linguistic features. These studies generally relate to syntactic/linguistic complexity.

However, the notion of syntactic/linguistic complexity is defined differently in the studies and comprises different combinations of individual linguistic features.

Results of the literature review in terms of how language features impose difficulties on learners

In the next step, the results of the studies in the different categories were interpreted in terms of how the language features affect students' solution processes or quality of solutions. The studies that have been assigned to the category *(in-)consistence of language* show controversial indications of the extent to which this feature influences the solution processes and quality of solutions. The two studies assigned to the category *pronouns* show no evidence that this feature influences the solution processes and the quality of solutions by learners. The overall view of the studies that were assigned to the category *vocabulary*, however, suggests that there is a fundamental translation problem on the procedural and conceptual level on the part of the learners and that possible difficulties cannot be explained by the feature *vocabulary* alone. The study that was assigned to the category *deictics* showed evidence that a certain type of error occurs particularly frequently in the field of algebra when the tasks contain indexical expressions. Since only one study was assigned to this category, a more comprehensive view of this language feature is not possible.

This broad overview already suggests that the hypothesis that difficulties of learners working on word problems can not necessarily be attributed to individual linguistic features. This is also supported by the study by Walkington et al. (2019). They analyse the influence of linguistic complexity by varying individual linguistic features of word problems separately and systematically. In this study, in total 451 American students from different school districts from grades 7 to 12 participated. The students were asked to complete different task variations that were presented on a free online homework platform. For this purpose, the word problems from the content area of linear functions were used. The tasks were systematically varied with regard the six different linguistic features mentioned earlier. Each feature was also varied in terms of three levels of difficulty. Students were not given any special instructions that they were taking part in a research study. The accuracy of the solutions and the reaction time were determined with the help of the digital platform. Overall, the authors were able to show that there is little evidence that individual linguistic features have a significant influence on students' performance in solving the word problems in the different grades. Therefore, the results of the studies classified as investigating linguistic complexity will be discussed in a differentiated way with regard to research question 1.2. Table 2 provides a more detailed overview of the studies in which the feature of *linguistic complexity* is discussed.

Table 2: List of studies on linguistic complexity of word problems classified by grade levels

Studies on linguistic complexity of word problems				
Grades 1 and 2	Grades 3 and 4	Grades 5 and 6	Grades 7 und 8	Grades 9 und 10
Ambrose and Molina (2014)		Muth (1984)	Leiss et al. (2019) Abedi and Lord (2001) Walkington et al. (2019)	Walkington et al. (2019)

Abedi and Lord (2001) investigated the influence of language in word problems on learners' performance. For this purpose, the authors conducted two separate field studies. The first study was a perception study. For this reason, in total 36 eighth graders at four school sites in the Los Angeles area were presented original NAEP (National Assessment of Educational Progress) maths items and parallel revised tasks in simplified language. The mathematical requirements were kept constant. In a standardized interview, learners were asked which tasks they would choose in an exam situation. Each learner had to answer this question for four pairs of tasks (original and modified). This study shows that the majority of the learners preferred the modified tasks to the original tasks. In the second study, the Accuracy Test Study, 1174 American students in grade 8 from 39 classes were given a paper-and-pencil math test. The test included 10 original NAEP math items, 10 items with linguistic modifications as described above, and five noncomplex control items. Two different test booklets were developed where the original items and modified items were developed comprising original and modified test items. Here, the students' scores on the original and linguistically modified items were compared. In principle, the linguistic modification also led to a significant difference in the mathematical performance of the learners. The modified tasks could be also handled better by the students, certain groups of learners particularly benefited from the linguistic modifications.

Leiss et al. (2019) reconstruct and investigate learners' comprehension processes when solving word problems and, among other things, address the question of what role task characteristics (complexity of the situation, linguistic complexity) play for the comprehension process. In their study, 55 seventh-grade German-speaking students attending three comprehensive schools were asked to complete three reality-based tasks on the topic of linear functions, which were systematically modified in terms of the complexity of the situation model and the linguistic requirements. The sessions took place under laboratory conditions and the students were required to solve the tasks by using the Think Aloud Method (p. 137). In this context, it was shown that the linguistic complexity influences the learners' comprehension more than, for example, the context into which the tasks are embedded.

The studies by Abedi and Lord (2001) and Leiss et al. (2019) showed that English-speaking learners are more likely to work on tasks with lower linguistic complexity. This means that the variations in the linguistic complexity (as defined by the authors) of the tasks resulted in a better understanding of the mathematical requirements by learners. In this context, it was also observed that tasks with lower linguistic complexity yielded higher rates of correct solutions. The results of Leiss et al. (2019) showed that the linguistic complexity of the tasks influences the comprehension of German-speaking learners more than the context of the task. At this point, it can be assumed that higher linguistic complexity (of different linguistic characteristics) can be understood as a feature that creates difficulties for learners.

In the two other studies, the feature of linguistic complexity was investigated using task examples from primary level. The main purpose of the study by Muth (1984) was to determine the relative importance of computational ability and reading ability to the solution of arithmetic word problems. Furthermore, Muth (1984) investigated how learners deal with different requirements imposed on them by different word problems. In this context, 200 sixth graders from two middle schools were asked to solve word problems that were modelled on NAEP tasks. Adding irrelevant information to the word problems forms a computational/problem solving demand in this study (p. 206). The

variation of syntax represents a reading-related demand (p. 206). These tasks were used to test learners' skills in addition, subtraction, multiplication, and division. Four versions of the test were created by developing two versions with variations in the additional information and two versions with variations in the complexity of the syntax. The results showed that the variation of syntax had no influence on the accuracy of the solution. Ambrose and Molina (2014) were able to show in a study that it were not so much the superficial linguistic features of the text, including syntax and vocabulary, that hindered the children's successful interpretation, but rather the situations and the limited information provided about them that affected comprehension. The study involved 18 first grade Spanish/English bilingual learners who were asked to retell and solve word problems in their first and second languages. Addition/subtraction and division tasks served as the mathematical content here. This contradicts the above-mentioned results by Leiss et al. (2019). There, the context of the task did not have as strong influence on the understanding of the tasks as the linguistic complexity for learners in seventh grade. A possible interpretation of these contradicting results of the two studies might be that learners in higher grades have more in-depth contextual knowledge than primary grade learners. The latter may need more detailed explanations on the context of the tasks in order to develop an appropriate understanding of the factual situation to be able to solve the task.

In summary, studies that varied single linguistic features show no clear influence on the learners' performance (Ambrose & Molina, 2014; Muth, 1984; Walkington et al., 2019). Studies in which several linguistic parameters were varied show evidence that lowering linguistic complexity leads to higher rates of correct solutions (Abedi & Lord, 2001).

Discussion

Summarising the results of the literature review to answer research question 1.1, it was possible to provide an overview of linguistic features that were investigated in previous research on word problems. Within the framework of this review, the following language features could be found: (*In-*) *consistency*, *personal pronoun*, *vocabulary*, *syntactic/linguistic complexity* and *deictics*. From these categories, *linguistic complexity* is conceptualized in different ways in the studies.

To answer the research question 1.2, first insights from the review of all studies were summarised and a differentiated review of the studies which were assigned to the category linguistic complexity was conducted. The language features (*in-*)*consistency*, *personal pronoun*, *vocabulary* and *deictics* appear to be features that are defined and used in the studies in a widely consistent way. Even if the research subjects in the studies differ to some extent, it is possible to draw careful conclusions about features that cause difficulties for learners. Considering the studies on linguistic complexity, which are linked to secondary school content, multiple variations were made (Abedi & Lord, 2001; Leiss et al., 2019). The results of these studies suggest that the features that generate difficulties cannot be attached to individual linguistic features, but rather the language as a whole system controls how mathematical demands of the task need to be perceived and mastered by learners. It has become apparent that learners perform better with reduced linguistic complexity (Abedi & Lord, 2001). The studies in which selected linguistic features were modified seem to confirm this hypothesis (Ambrose & Molina, 2014; Muth, 1984; Walkington et al., 2019). Linguistic complexity as a genre feature seems to be a phenomenon that takes on different forms.

In terms of limitations, it should be noted that only a small number of studies were considered in this paper and the conclusions need to be substantiated by further studies. In the further course of this project, the analysis presented in this paper will be used as a starting point to carry out a task analysis with the aim to describe the connection between the language and the mathematical content in a more differentiated way with a particular focus on how the mathematical and linguistic demands of word problems develop across primary and secondary mathematics curriculum.

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