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The influence of reading comprehension on solving mathematical word problems: A situation model approach

1 Introduction

Tasks presenting mathematical information as text, known as word problems, are one of the key components in the teaching of mathematics in primary school. Still, they are also one of the most difficult ones. Studies have revealed that word problems are solved up to 30% less successfully than tasks in numerical notation (Duarte et al., 2011). This discrepancy indicates that besides mathematical competence aspects of language play a significant role in the processing of word problems as well (Duarte et al., 2011; Gürsoy, 2016; Heinze et al., 2011; Prediger et al., 2015; Verschaffel et al., 2000). In order to solve a word problem, students not only need to perform the necessary mathematical operations, they also need to understand the text of the task.

There are two intertwining factors central to understanding the text of a word problem: the task text itself and the problem solver's individual reading competence. Both can cause difficulties. In recent years, increasing attention has been paid to the task text and its linguistic characteristics that are considered to challenge the processing of the task, such as academic language (Abedi & Lord, 2001; Gürsoy, 2016; Haag et al., 2015; Martinello, 2008; Prediger et al., 2015). However, there have only been a few studies that focus on reading skills as a factor in explaining students' difficulties in dealing with word problems. Since reading and understanding the text of a task are fundamental for solving word problems, it can be assumed that, in addition to the linguistic characteristics of the task text itself, reading competence also has an important influence on the solution process.

Hence, the present study examines the impact of reader characteristics on the handling of word problems in primary school and explores aspects of reading competence that may be relevant for their solution. Putting mathematical content and processes aside, word problems are primarily texts that have to be read and understood. In addition to the mathematical perspective on solving word problems (Section 2), the reading process is therefore examined from a cognitive-psychological perspective to transfer relevant conclusions to mathematics (Section 3). This may lead to important conclusions on ways of promoting

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mathematical reading skills. The empirical part (Sections 4 and 5) describes the study carried out on the relationship between various aspects of reading competence, mathematical competence, and the probability of solving word problems. Finally, the results regarding their impact on teaching mathematical word problems are discussed (Section 6).

2 Solving mathematical word problems

Mathematical word problems are mathematical exercises whose main characteristic is the embedding of mathematical relations in a text rather than in a mathematical notation (Duarte et al., 2011), for example, "Peter has 3 marbles and Ann has 5 marbles. How many marbles do they have altogether?" The context of the tasks varies and ranges from excerpts from students' everyday lives to facts and figures and fantasy worlds. Word problems pursue three goals: the application of mathematics, the development and expansion of problem-solving skills, and the exploration of the environment by means of mathematics (Franke & Ruwisch, 2010).

Solving word problems is complex and includes several stages (Blum & Leiss, 2007; Verschaffel et al., 2000). The modeling cycle of Blum and Leiss (2007) shown in Fig. 1 illustrates the cognitive operations during the solution process.

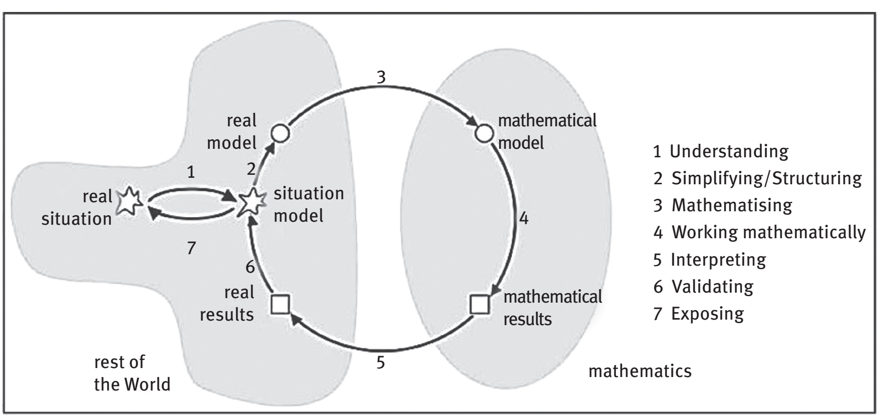

Fig. 1: Modeling cycle (Blum & Leiss, 2007).

At the beginning of the process, the word problem has to be read and (1) the problem situation has to be understood. During the reading process, a situation model, that is, a mental representation of the initial situation described in the text, is generated. In a next step, a (2) real model has to be formed through processes of simplification and structuring. The real model contains only certain features essential for processing the task, meaning that every information is excluded from the situation model that is not necessary for computation. (3) Mathematizing transforms the real model into a mathematical model, which contains relations between relevant elements, numbers, variables, and so forth and is created by incorporating mathematical concepts. This process is not a one-to-one translation between the real model and the mathematical model, but rather a constructive act that depends, among other things, on the objectives and mathematical knowledge of the problem solver (Franke & Ruwisch, 2010). Finally, by (4) working mathematically, that is, performing mathematical operations, the result is calculated, and interpreted with respect to real-life situation (5) and validated with respect to the situation model previously constructed (6). The modeling cycle ends with the (7) exposition and explanation of the solution. Metacognitive strategies "check" the processes for plausibility throughout the entire modeling process, and lead, if necessary, to a restart of the cycle or individual sub-processes.

Empirical evidence suggests that the construction of a situation model is crucial for processing word problems successfully (Hegarty et al., 1995; Kintsch, 1998; Reusser, 1989; Thevenot, 2010).

Depending on the text and the problem solver's individual characteristics such as goals, mathematical knowledge, language and reading skills, and metacognitive abilities, the processing of tasks can be less linear than described above. Difficulties can occur in all sub-processes. In particular, the construction of a situation model and a real model can be a major obstacle for learners (Greefrath et al., 2013; Hegarty et al., 1995; Verschaffel et al., 2000). Therefore, often inadequate strategies are used that usually do not result in a correct solution. Frequently used strategies are the immediate calculation with the given numbers without reading the text and the orientation toward alleged keywords such as "more" or "less," which are directly translated into a mathematical operation that seemingly fits the keyword (addition, respectively subtraction), simultaneously ignoring the particular context. Consequently, key sub-processes such as the construction of a situation model are skipped (Hegarty et al., 1995; Verschaffel et al., 2000). Thus, Hegarty et al. (1995) speak of a "direct translation strategy" (p. 18) in contrast to the "problem model strategy" (p. 18).

However, the processes involved in building a situation model are not the primary concern of mathematical research, which is why conclusions about the situation model concerning word problems remain somewhat vague.

Building a situation model is a decisive process not only for solving word problems but also for reading comprehension in general. As word problems are texts that have to be read and understood, it is crucial to give an in-depth examination of the construction of the situation model from a text comprehension perspective to gain insights into possible reasons for difficulties during problem solving.

There are only a few studies that deal with the relationship between reading comprehension and word problems and even less that focus on the construction of a situation model. Nevertheless, these studies provide evidence that reading competence plays an important part in solving word problems (Boonen et al., 2016; Capraro et al., 2012; Fuchs et al., 2015; Jordan et al., 2003; Leiss et al., 2019; van der Schoot et al., 2009). So far, however, little attention has been paid to the sub-processes involved in the construction of the situation model while reading word problems. Thus, the aim of the present study is to shed light on these sub-processes and their relevance for the solution of word problems.

Hence, in the next section, the processes involved in building a situation model will be closely examined from the psychology of reading point of view, in order to derive indications for factors affecting reading and understanding word problems for the empirical study.

3 Text comprehension

The complex process of reading is composed of several sub-processes. At word level, these include the basic processes of letter and word recognition as well as the acquisition of word meaning. At sentence and text level, syntactic and semantic relationships between words and sentences have to be established and transformed into a coherent meaning of the text by integrating previous knowledge (Christmann & Groeben, 1999; Richter & Christmann, 2009).

Recognizing the meaning of words is undeniably crucial for reading comprehension. However, understanding texts is more than just decoding single words. Current theoretical approaches assume that comprehension requires the construction of multiple mental text representations (Graesser et al., 1994; Kintsch, 1998; Schnotz, 2006). Three main levels of text processing are distinguished:[1] the surface level of the text, the text base, and the level of the situation model (Kintsch, 1998; Schnotz, 2006). As the construction of a situation model is the core process of text comprehension, the following section focusses on these processes without considering basic reading processes.

1 In current research, additionally a communication and a genre level are assumed. Schnotz and Dutke (2004) refer to the latter as meta-levels since they do not represent facts described in the text, but rather characteristics of the situation in which a text is received.

3.1 Construction of a situation model

The *surface level* represents the entire linguistic information of a text, for example, the literal wording and syntactic constructions (Graesser et al., 1997). A mental representation of the text surface arises from processes of recoding and parsing. Semantic processing does not yet take place on this level. The following example of a pseudo-sentence with fake words illustrates these processes: "The ploor proy yegged." When processing this pseudo-sentence, the grapheme-phoneme correspondence is established, and syntactical parsing is carried out. Thus, for instance, even without understanding the meaning, one can easily identify the noun in the sentence ("proy"). On this level of word processing, it is therefore possible to reproduce sentences literally without understanding their meaning. It is assumed that the mental representations of the text surface form the structural basis for higher semantic representations (Schnotz, 2006).

Cognitive theories agree that the semantic information of the text is transferred into a mental representation, the so-called *text base*. The text base represents the semantic content of a text (Kintsch, 1998; van Dijk & Kintsch, 1983). As texts consist of single pieces of semantic information, semantic relations between these pieces must be established in the process of text comprehension, so that a mental network is created. At the level of the text base these connections are established by means of inference that are text-based and do not require any extra-textual knowledge, such as creating co-reference with pronouns (Graesser et al., 1997). The emerging mental network is at best locally coherent because there is no top-down processing integrating the reader's background knowledge on this level.

The use of prior knowledge is essential for global text comprehension since texts do not explicitly represent all the information necessary for a complete reconstruction of the meaning (Schwarz, 2001). The missing references have to be established by the recipient taking into account his or her background knowledge. Hence, the construction of a text base allows only for shallow comprehension without establishing global connections and a deeper meaning and is therefore insufficient for the understanding of texts (Schnotz, 2006). The integration of textual information with the reader's knowledge into a coherent mental representation of the text, a so-called situation model is crucial for text comprehension.

A *situation model* is "a cognitive representation of the events, actions, persons, and in general the situation that a text is about" (van Dijk & Kintsch, 1983: 11). The situation model built on the sentences "Peter has three marbles and Ann has five marbles. How many marbles do they have altogether?" could be the imagination of two kids sitting on the pavement combining their marbles. The construction of a situation model is an integrative and step-by-step process: On the one hand, relations between sentences are established during reading, and on the other hand, the situation model constructed so far forms the context for the interpretation of the next sentence. Thus, an extended new model is created, which in turn provides the context for the interpretation of the next passage of text. During this process, explicit information from the text is integrated with the reader's prior knowledge from long-term memory (Garnham & Oakhill, 1996; Kintsch, 1998). This includes linguistic knowledge as well as knowledge of the world or expert knowledge (Nussbaumer, 1991).

The successful drawing of *inferences* is crucial for the construction of a situation model. Two types of inferences are particularly relevant here: "Local Cohesion Inferences" and "Global Coherence Inferences" (Graesser et al., 2007; Oakhill et al., 2015), the former often referred to as "bridging inferences" (Graesser et al., 2007; Kintsch, 1998). "Local Cohesion Inferences" are used to create references at a local level within and between sentences. Anaphora like pronouns and connectives are important linguistic means for establishing local connections. "Global Coherence Inferences" establish global coherence by connecting larger parts of the text in the situation model. They are more important for text comprehension than "Local Cohesion Inferences." Global inferences are knowledge-based; that is, they cannot be drawn without extra-linguistic prior knowledge. Since inference making depends on a number of different impact factors, different readers might create situations models of the same text that might vary widely in character and complexity (Kintsch, 1998).

3.2 Impacts on the construction of a situation model

Text comprehension is a complex process involving the interaction of different mental sub-processes. Individual differences in mastering these processes lead to difficulties in constructing mental representations. Parameters affecting the construction of a situation model are mainly inference skills and metacognitive skills such as the ability to monitor one's own understanding (Oakhill & Garnham, 1988). These aspects will be examined in more detail below.

3.2.1 Inference skills

Oakhill and Garnham (1988) assume that individual differences in inference making are responsible for differences in the construction of situation models and thus for text comprehension. In a longitudinal study, Oakhill and Cain (2012) investigated factors influencing text comprehension in eleven-year-old children.

They were able to show that the ability to build inferences during reading of seven- and nine-year-olds is the critical predictor of later text comprehension. Decoding ability and implicit syntactic knowledge, however, had no predictive power on text comprehension in eleven-year-olds. The ability to draw inferences during the reading process develops over the course of schooling, independently of the learners' prior knowledge (Barnes et al., 1996; Oakhill & Garnham, 1988). Klicpera and Gasteiger-Klicpera (1993) demonstrated that third graders had difficulties in drawing inferences despite a high level of prior knowledge. The ability to draw necessary inferences during the reading process not only distinguishes younger from older children, but also differentiates decisively between competent and less competent readers. Studies reveal that children with lower text comprehension skills draw fewer inferences than good readers, despite having the same prior knowledge. Difficulties in drawing inferences and thus in constructing a coherent situation model can be the result of a lack of prior knowledge or insufficient retrieval of knowledge, poor processing of anaphors and connectors, limited working memory capacity, and limited vocabulary knowledge.

Vocabulary knowledge is essential for text comprehension and also for drawing inferences. A broad mental lexicon supports the construction of a situation model (Oakhill et al., 2015; Oakhill & Garnham, 1988; Schnotz & Dutke, 2004). However, vocabulary is not the only factor in determining text comprehension.

A large number of studies have found that a possible explanation of individual differences in drawing inferences is rooted in the extent of *prior knowledge* (McNamara et al., 2011). Regardless of their reading skills, children who had the most background knowledge about the topic of the text they had to read scored best in these studies. Children with low-level reading skills but a high level of prior knowledge outperformed children with high-level reading skills but low-level prior knowledge in the number of correct inferences (Adams et al., 1995; Recht & Leslie, 1988; Schneider & Körkel, 1989). Further studies revealed that prior knowledge influences mainly the situation model level and hardly the text base. Readers with little background knowledge do not construct a global situation model during reading, but rather build up a text base (Dutke, 1993; Fincher-Kiefer et al., 1988). This is because many pieces of information remain unconnected in long-term memory. Kintsch (1998) refers to "many different unconnected islands" (p. 232), because the necessary knowledge to establish connections is missing. However, a lack of prior knowledge does not completely explain the problems that occur during inference making. Even if poor readers have background knowledge, they often seem to be unable to retrieve this knowledge sufficiently from long-term memory to draw inferences or fail to integrate prior knowledge into information drawn from the text. Thus, poor readers may not know when to draw inferences (Cain & Oakhill, 1999; Cain et al., 2001).

Anaphora resolution and understanding *connectives* are crucial for drawing local inferences. The ability to resolve pronouns while reading develops during primary school is critical. For example, children up to the age of 10 still find it difficult to use the context when resolving syntactically ambiguous pronouns (Oakhill et al., 2015). In particular, children with lower-level reading skills often have difficulties in resolving pronouns. They frequently tend to interpret the noun closest to the pronoun as an antecedent (Megherbi & Ehrlich, 2005). This may be due to lower working memory capacity. The distance between pronouns and antecedent thus plays a role in pronominal resolution and in the process of comprehension (Daneman & Carpenter, 1980; Oakhill et al., 2015). Since in German not only semantic but also syntactic clues are relevant for the resolution of pronouns, such as the consistency of the grammatical gender, this can also result in difficulties, especially for second-language learners.

Connectives are gradually acquired while children are still of primary school age. Regarding the English language, acquisition patterns reveal that additive connectives are acquired first, followed by temporal, causal, and finally adversative connectives (Bloom et al., 1980). As regards the German language, Dragon et al. (2015) demonstrated throughout different studies that second and third graders, whose first or second language was German, processed temporal and causal connectives with high frequency significantly better than concessive connectives, regardless of the language spoken at home. Differences between children only speaking German at home and those who spoke another language with family members were, if at all, only marginally present and therefore of no practical relevance.

Working memory is relevant for both global and local comprehension. Information that is spread across the entire text must be maintained in memory and integrated into the situation model created so far. At local level, for example, the referential words for pronouns have to be maintained. A lower working memory capacity leads to a reduced ability to link information from the text to prior knowledge which hinders the creation of a coherent global situation model. The capacity and processing efficiency of the working memory develop throughout childhood. In children with below-average text comprehension skills, it has been found that working memory performance is a distinguishing factor as compared to good readers, especially when the information which has to be integrated does not occur in adjacent sentences, but is located further apart (Oakhill et al., 2005).

3.2.2 Metacognition

Children with good and lower-level text comprehension skills differ in the strategies they consider appropriate for reaching specific reading goals. Similarly, below-average readers often have different individual theories about reading compared to good readers (Cain, 1999). “They tend to view reading as a word decoding activity rather than one of meaning-making” (Oakhill & Cain, 2007: 67). Even those having good decoding ability tend to focus on word reading. Thus, their reading aim is more directed toward understanding individual words. The establishment of references and the understanding of the text as a whole are not focused (Garner, 1981; Oakhill & Cain, 2007; Oakhill et al., 2015; Oakhill & Garnham, 1988). Oakhill et al. (2015) accordingly state, “If reading is all about ‘getting the words right’ then a high standard for comprehension will not be set” (p. 105). Contrary to good readers, children who read a text word by word do not expect to build up a coherent situation model of the text when reading it. Oakhill and Cain (2007) refer to this as a lower “standard for coherence – caring that a text makes sense” (p. 67). A low “standard for coherence” leads to less or no inferring and, thus, no global situation model is established. According to Schnotz (1994), in this case, one can speak of an “illusion of understanding” (p. 208). Therefore, less efficient readers are not aware of their comprehension problems at all. Thus, they regard further activities aimed at optimizing comprehension as pointless, although a coherent situation model has not yet been established. Consequently, there is hardly any monitoring of the reading process; otherwise, problems of understanding would be noticed (Cain, 1999; Schnotz, 1994). However, constant monitoring of one’s own reading process is critical to ensure text comprehension. New information has to be compared with the previously formed situation model and checked for inconsistencies and plausibility.

4 The current study

Empirical studies demonstrate that the construction of a situation model is crucial for solving word problems. However, the situation model is not the focus of current research when it comes to students’ difficulties in solving word problems. As word problems are texts that have to be read and understood, in line with the theoretical background presented, it is to be assumed that the aspects relevant for the comprehension of non-mathematical texts also have an effect on the construction of a situation model when reading mathematical texts. It is important to examine more closely, which reading skills contributing to the construction of a situation model also contribute to solving mathematical word problems and how these skills are related. This knowledge is vital to shed light on non-mathematical aspects that make it challenging to solve word problems and to purposefully promote "mathematical" reading comprehension. In order to do so, the study at hand includes measures of different skills of text comprehension relevant to the construction of a situation model, rather than a global assessment of reading competence.

The study addresses the following questions: Does the ability to construct a situation model influence the solution of word problems? Do inference skills make a contribution to the solution process of word problems? Are comprehension monitoring and standard for coherence also important parameters for dealing with word problems? How do mathematical processes and reading processes interact when solving word problems?

The relationships examined here should apply at least to children without special educational needs, regardless of their language or reading skills since the cognitive processes behind reading competence are not fundamentally different in first- and second-language learners. Therefore, there are no differences expected to be observed between students with German as first and German as second language. That is not to assume that there are no differences in the level of reading competence and the solving of word problems between those students, but these are not further examined in the present study, as this study focuses on relationships between reading subskills and solving word problems.

4.1 Method

The design of the study is correlational. Nevertheless, some hypotheses about the direction of relations were formulated and being tested by means of a structural equation model. Structural equation modeling is a statistical procedure that incorporates the relationship of latent variables and confirms hypotheses about the validity of measurements. This particular model is based on the theoretical findings and assumptions described in the overview above. The goodness of fit of the parameters was decisive for the evaluation of the model. A total of three variants of the model were calculated, one overall model with all participants and one model each for L1 and L2 learners in order to compare these subgroups.

The reliability of the different measures was assessed by calculating Cronbach's alpha, whenever this measure was applicable. The present study is part of a broader project on the relationship between language and mathematical word problems (Stephany, 2018).

4.2 Participants

A total of 381 fourth graders from seven schools participated in the study. Children with special educational needs, diagnosed dyslexia or dyscalculia as well as children who had only been learning German for a few weeks were excluded from the analysis. The resulting sample comprised 352 students aged between eight and eleven years (M = 9.05; SD = 0.47), 47.9% were girls, 39.3% of the children spoke German as their second language. The schools were located in a range of lower- to middle-class urban areas.

4.3 Assessments and material

4.3.1 Reading skills

Some tasks were used from standardized tests and others were developed to measure specific components of comprehension skills notably necessary for the construction of a situation model in the three following areas: inference skills, comprehension monitoring, and the standard for coherence. Additionally, word-reading ability was measured.

4.3.1.1 Inference skills

The ability to establish local and global references was measured with the ELFE 1–6 subtest “text comprehension” (Lenhard & Schneider, 2006). Children read short stories, and for each one they had to select one out of four statements that fits the text the best. It was evaluated how well children established anaphoric references or build inferences. The reliability of the subtest “text comprehension” was $\alpha = .76$. A factor value “inference skill” was calculated with both variables.

4.3.1.2 Comprehension monitoring

An inconsistency detection task was used to measure comprehension monitoring. Children read two short stories containing internal inconsistencies. One line at the beginning and at the end of each of the stories contained contradictory information (Oakhill et al., 2005). Children were asked to underline any parts in the stories that did not make sense. Inconsistencies between parts of texts can be detected only by a continuous comparison with the situation model constructed so far. Correlation between the inconsistency items in both stories was $r = .30$ ($p < .001$).

4.3.1.3 Standard for coherence

Based on the considerations of Garner (1981), Oakhill and Cain (2007), and Oakhill and Garnham (1988), a questionnaire was constructed in order to find out if children tend to be "word readers" with a low "standard for coherence." The term "word readers" is used for children who consider reading to be exclusively a decoding activity, that is, who read a text word by word. "[They] manage written language as bits and pieces, not as textual wholes" (Garner, 1981: 161). A questionnaire with seven items was developed. Each item consisted of two conflicting statements: one reflected the strategy of word by word reading, and one statement focused on text comprehension. Some of these statements were used several times in different combinations. The polarity of the statements was randomized. The children were asked to choose one of the statements. All items were assigned to three superordinate questions: "What makes a good reader?" "What makes a text difficult to read?" and "When are you satisfied with yourself when reading?" Fig. 2 shows an excerpt from the questionnaire. Cronbach's alpha for all seven items was $\alpha = .53$. This is only moderate but sufficient for scientific purposes.

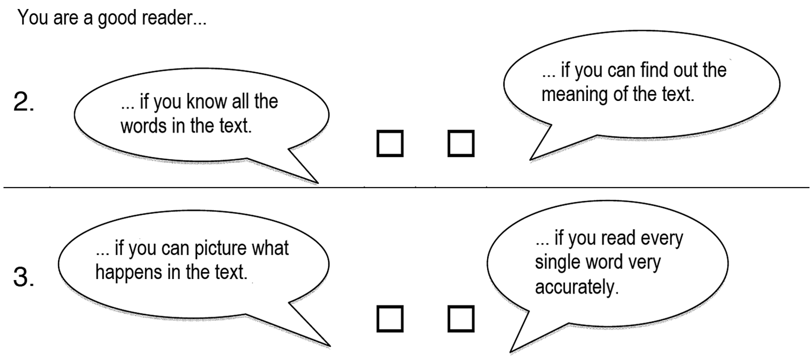

Fig. 2: Excerpt from the reading questionnaire.

4.3.1.4 Word-reading ability

Word-reading ability was controlled in the study. All children completed the subtest "word comprehension" of the German reading comprehension test ELFE 1–6 (Lenhard & Schneider, 2006). Children had to underline the word that matched a picture. The reliability of the test was high ($\alpha = .94$).

4.3.2 Mathematical skills

4.3.2.1 Mathematical ability

The subtest "Arithmetic" of the German Mathematics Test DEMAT 3+ (Roick et al., 2004) was used to assess arithmetic competence. The reliability of the subtest "arithmetic" was $\alpha = .77$. In addition, the grades of the participating students in mathematics were elicited.

4.3.2.2 Mathematical reading competence

To assess if children tend to use a direct-translation strategy in contrast to a problem-model strategy a test consisting of three word problems was developed, which contained additional numerical data that was irrelevant for answering the questions. The children first had to circle the numbers they needed for the calculations and then they had to solve the tasks. Cronbach's alpha was $\alpha = .89$. To calculate a value "mathematical reading competence" the circled numbers and the numbers actually used for calculating were combined with factor analysis.

4.3.2.3 Word problems

To assess the ability to solve word problems, four word problems with two different grades of text coherence were developed ("koala," "tortoise," "swallow," "ant eater"). This approach controls for the influence of text coherence on the development of a situation model. All tasks used the topic "records in the animal world." Fig. 3 shows one version of the word problem "tortoise."

> Riesenschildkröten sind die ältesten Tiere der Welt. Sie werden häufig über 200 Jahre alt. Die älteste bekannte Riesenschildkröte Adwaita lebte 140 Jahre in einem indischen Zoo. Sie wurde aber erst im Alter von 116 Jahren gefangen. Wie alt wurde sie?
>
> Giant tortoises are the oldest animals in the world. They often grow over 200 years old. The oldest known giant tortoise, Adwaita had lived for 140 years in an Indian zoo. However, it was captured only at the age of 116 years. How old did it get?

Fig. 3: Word problem "tortoise" in German and translated into English.

With regard to their mathematical content, all word problems corresponded to the curricular requirements in the field of elementary arithmetic for the fourth grade. When creating the tasks, it was ensured that in no case a "direct translation strategy," that is, an exclusive orientation toward numbers and supposed key words, could lead to the correct solution.

4.3.3 Situation model

A central aspect of the present study was the assessment of the situation model. The few studies available in mathematics assess the construction of a situation model indirectly either by rating the tasks (Leiss et al., 2010) or by using the correct solution as an indicator. In contrast to them, in this study the situation model was measured via images and statements matching the word problem. Thus, the situation model was measured independently of mathematical processes.

In order to obtain a value for the construction of a situation model, three images and four statements for each word problem were developed. One image represented the global topic of the word problem (attractor); two images served as distractors. Fig. 4 shows the images of the word problem "tortoise." Children were asked to select the pictures depicting the word problem. In order to select the corresponding image, the construction of a situation model of the task text is required, which needs to be validated against the content of the images (Schnotz & Dutke, 2004).

Furthermore, children were asked to decide whether statements about the word problem were true or false. For instance, the correct answer required the inference of local ("The giant tortoise Adwaita was the oldest animal in the world.") and global ("The time in freedom and the time in the zoo altogether add up to the age of the tortoise Adwaita.") connections in the text of the task. The correct evaluation of the global statement required the construction of a coherent situation model of the word problem. To calculate a value "situation model" for each word problem students' answers on images and statements were summarized with the help of a factor analysis.

4.4 Procedure

Data collection took place in seven schools after the summer break in a classroom assessment. The tests were conducted by the author on different days. The total assessment time per student was 75 min. Each student completed all four word problems, two high and two low coherent versions. Images and statements had to be processed after solving each word problem without viewing the

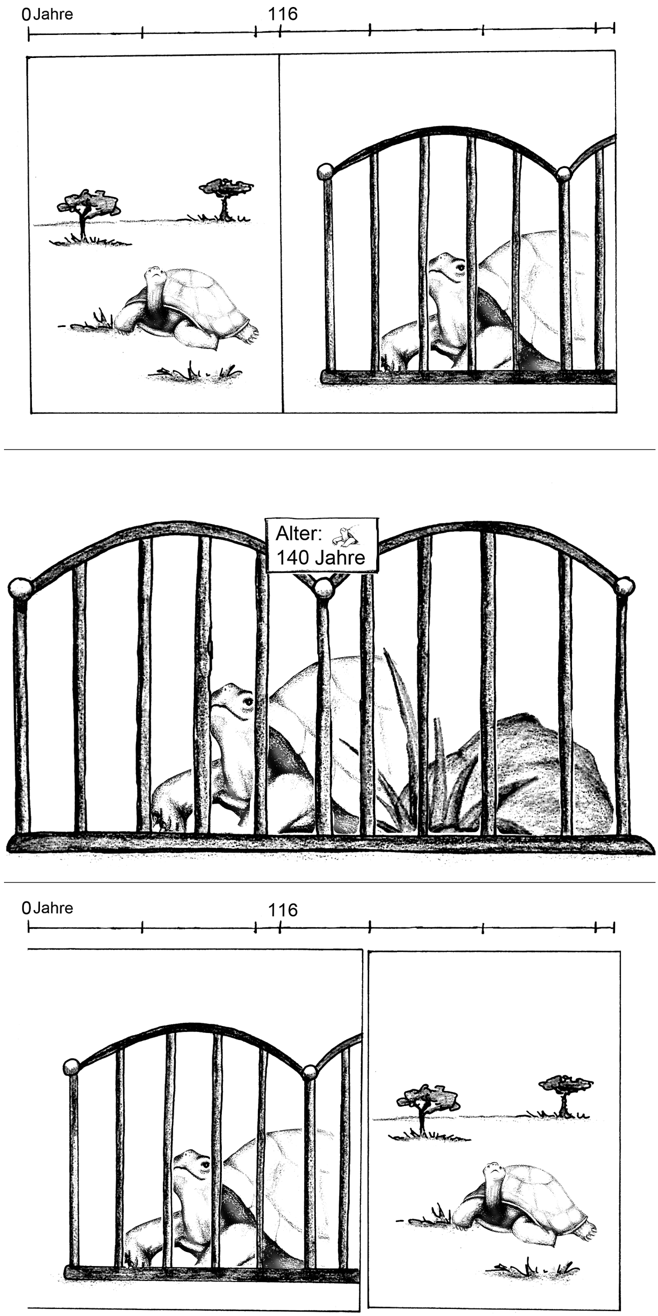

Fig. 4: Image to measure the situation model "tortoise.".

text. Thus, the situation model was supposed to be captured at the time of task processing without being distorted by re-reading the text. In order to rule out the possibility that word problems are not solved solely due to a lack of prior knowledge on the topic of the tasks, this likelihood was controlled by activating and building vocabulary and knowledge on the topic.

5 Results

The hypothesized relationships among variables were evaluated by means of structural equation modeling. Since not all variables could be transformed into a latent construct, manifest variables are also represented in the model. Fig. 5 depicts the model for all participants. The model's paths and path directions were derived from a variety of studies and theoretical expectations. To evaluate the fit of the model the root-mean-square error of approximation (RMSEA) was used. The results indicate that the fit of the proposed model was good RMSEA = .068; Chi-square was 146.15 (df = 56), $p < .001$. These results suggest acceptance of the proposed model as the most parsimonious. The standardized and unstandardized regression weights and the significance levels of these variables are depicted in Tab. 1.

5.1 Confirmatory part of the model

Before evaluating the structure model, it is investigated whether the manifest variables make an actual contribution to the respective latent construct. The "situation model" was assessed through the pictures and statements concerning the four word problems. These variables (pictures and statements) were combined into a single factor entering the structural equation model. The confirmatory part of the structural equation model reveals a moderate fit of these four variables to the latent construct "situation model." The loads of the single variables ranged between .24 and .74. The variables measuring "mathematical performance," arithmetical skills and math grade, loaded between .73 and .86 and thus showed a good fit. Although the factor was constructed by mathematical skills, it is named "performance" since in the modeling cycle, problem solvers have to perform math based on their skills. The latent factor "solution" measured by the variables correct solution path and result (.97 each) also demonstrates a good model fit.

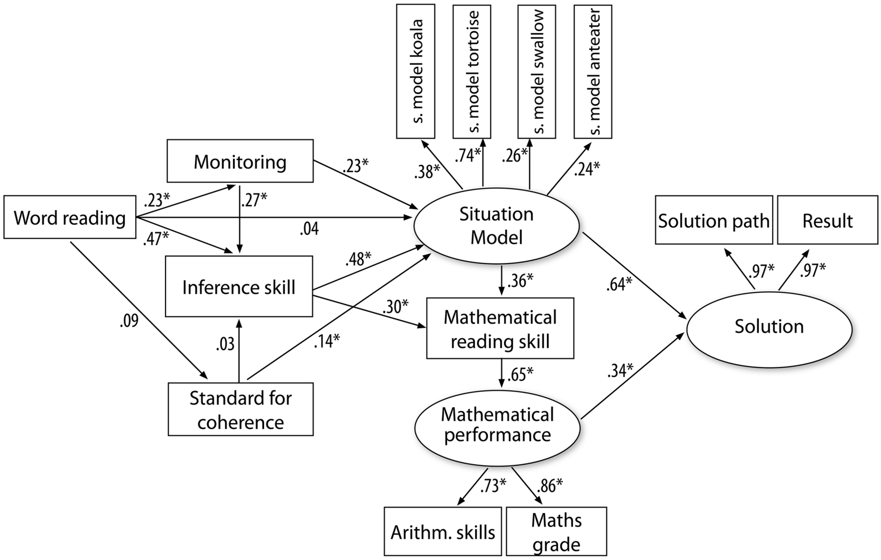

Fig. 5: *Structural equation model for the processing of word problems – all students.* Rectangles represent measured variables; circles represent latent factors. Measurement errors and structural errors were removed from the figure. Significant and non-significant paths are displayed; * = path coefficient $p < .05$; s. model = situation model.

Tab. 1: Standardized and unstandardized regression weights and their levels of significance.

			Unstandardized regression weight	Standardized regression weight	S.E.	C.R.	p
Word reading	→	Monitoring	0.19	.23	0.042	4.428	<.001
Word reading	→	Standard for coherence	0.10	.09	0.057	1.755	.079
Word reading	→	Inference skill	0.50	.47	0.048	10.235	<.001
Monitoring	→	Inference skill	0.36	.27	0.061	5.943	<.001
Standard for coherence	→	Inference skill	0.03	.03	0.044	0.656	.512
Standard for coherence	→	Situation model	0.10	.14	0.040	2.574	.010
Monitoring	→	Situation model	0.23	.23	0.059	3.821	<.001
Word reading	→	Situation model	0.03	.04	0.050	0.643	.520

Tab. 1 (continued)

			Unstandardized regression weight	Standardized regression weight	S.E.	C.R.	p
Inference skill	→	Situation model	0.35	.48	0.053	6.670	<.001
Inference skill	→	Mathematical reading	0.28	.30	0.071	3.926	<.001
Situation model	→	Mathematical reading	0.46	.36	0.117	3.916	<.001
Mathematical reading	→	Mathematical performance	0.54	.65	0.048	11.286	<.001
Mathematical performance	→	Solution	0.56	.34	0.095	5.913	<.001
Situation model	→	Solution	1.12	.64	0.128	8.727	<.001

Notes. S.E. = Standard error, C.R. = critical ratio.

5.2 Structural part of the model

In consideration of the structural part of the model, there was a high connection between the construction of a situation model and the solution ($\beta = .64$). The relationship between mathematical performance and the solution was considerably smaller ($\beta = .34$). In this model, the ability to solve word problems was composed of both the skill to construct a situation model and mathematical performance. However, the construction of the situation model was a much better predictor (and prerequisite) for correct solutions. Although the variable solution model explained around 41% of the total variance in solving word problems, mathematical performance explained only 11.6% of it.

The differences in the ability to build a situation model when solving word problems were explained by 42% of the variance in inference making, monitoring the reading process and the standard for coherence. Furthermore, monitoring the reading process had a moderate, yet significant, impact on inference making ($\beta = .27$) and a direct path to the situation model ($\beta = .23$). Higher-level reading processes are, therefore, responsible for building an adequate situation model. Word reading had an impact on monitoring ($\beta = .23$) and inference making ($\beta = .47$). The direct path from word reading to the latent factor situation model was somewhat weaker ($\beta = .04$, n.s.) than the path from inference making – situation model ($\beta = .48$), meaning higher-order reading skills have a higher impact on the construction of a situation model than basic reading skills, at least when reading word problems.

According to the model, 35% of the variance in mathematical reading could be explained by inference skills ($\beta = .30$) and the situation model ($\beta = .36$). Mathematical reading, on the other hand, correlated strongly with mathematical performance ($\beta = .65$), and thus explained 42% of the variance in mathematical performance.

5.3 Differential aspects of learning German as first or as second language

To analyze the differential aspects between L1 and L2 learners, two different models were calculated. It was assumed that the interconnections in the L2 model are not substantially different from those in the L1 model, because the cognitive processes underlying reading competence are not fundamentally different in first- and second-language learners. A closer look at both models (Fig. 6) shows that this assumption can largely be supported since only marginal differences are revealed.

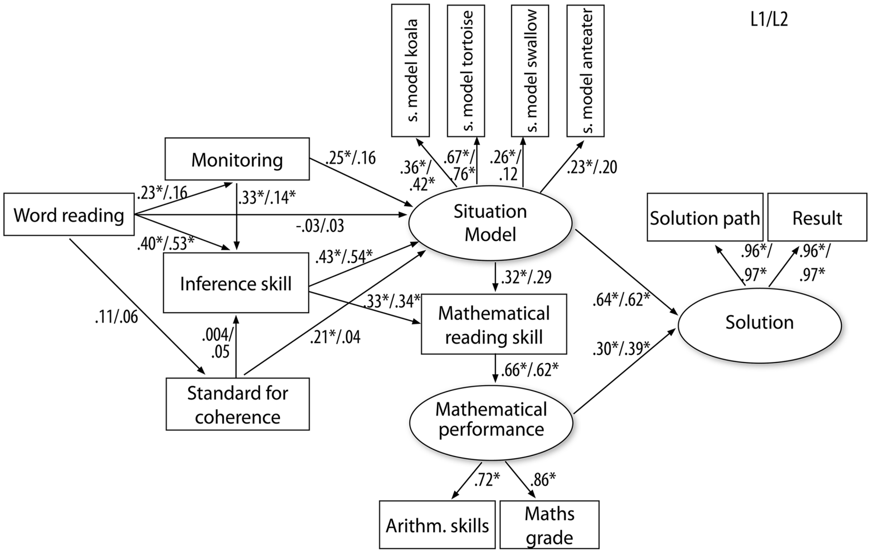

Fig. 6: *Structural equation model for the processing of word problems – German as a first and as a second language.* Rectangles represent measured variables; circles represent latent factors; measurement errors and structural errors were removed from the figure. Significant and non-significant paths are displayed; * = path coefficient $p < .05$; s. model = situation model; values show L1/L2.

The core idea of this paper referred to the connection between the construction of a situation model and the solution of word problems. The part of the model that refers to this relationship shows no substantial differences between L1 and L2 learners. However, minor variations in the overall model were found concerning the variables involved in the construction of a situation model. It was found that the ability to decode words had the same minor effect on the construction of a situation model in L1 and L2 learners. The influence of inference making and monitoring the construction of a situation model was slightly different in both groups. However, these differences are marginal and are not of any practical relevance. The only substantial difference was found in the connections between the "standard for coherence" and the "situation model" among L1 and L2 learners (higher correlation for L2 than for L1). This could be due to only a moderate reliability of the questionnaire or a poor understanding of the items.

It was revealed that the effect of the variables "monitoring," "inference making," and "standard for coherence" on the construction of an situation model are composed slightly differently for L1 and L2 learners. However, this is hardly of any practical relevance. The variance of the situation model explained by the three variables monitoring, inference making, and standard for coherence was about 39% both for L1 and L2 learners. Hence, the joint influence of these variables was the same for both groups. In conclusion, the relevance of an adequate situation model for solving word problems is equally high for both groups.

Both SEM showed a good fit of the RMSEA ($RMSEA_{L1} = .077$, $n = 214$; $RMSEA_{L2} = .045$, $n = 138$). Chi-square was significant for L1 but not for L2 ($Chi\text{-}square_{L1} = 122.39$ ($df = 56$), $p < .001$; $Chi\text{-}square_{L2} = 1{,}024$ ($df = 56$), $p = .085$). Due to the smaller number of L2 participants in contrast to the L1 model, more paths do not reach significance.

6 Discussion

In this contribution, word problems were presented as texts that have to be read. To solve a word problem, students not only need to perform the necessary mathematical operations, they also need to read and understand the text of the task. Therefore, it was assumed that one reason for students' difficulties with word problems relates to reading processes, in particular to processes involved in the construction of a situation model. In recent years, an increasing number of studies focused on language-related reasons for complications with word problems. In doing so the main focus was on the task text itself and its linguistic features. Only a few studies examined students' reading competences and even fewer focused on the problem solvers' ability to construct a situation model, in order to explain difficulties and give guidance to foster the solving of word problems in the classroom. The present study sheds light on the sub-processes necessary for building a situation model known from psychological reading research.

With the help of various standardized as well as specifically developed measurement tools, a structural equation model was created to provide answers to four questions concerning the role of the situation model and the factors involved in its construction in the context of mathematical word problems.

It has been revealed that the situation model has a strong direct effect on the solution of word problems. This effect is even much stronger than the influence of mathematical performance on the correct solution. This indicates that not only mathematical competence but also the construction of a situation model is crucial for the solution of mathematical word problems. If no situation model is constructed, as in the "direct translation strategy," it is usually not possible to solve the task. Since the present model confirms the relevance of the situation model also for mathematical word problems, it is even more important to closely examine the factors influencing the construction of a situation model. The ability to draw inferences has the strongest influence; that is, children who draw few inferences also construct a situation model less well, and the frequency of solutions is correspondingly lower.

Furthermore, reading-related metacognitive strategies were considered. The model shows a significant influence of comprehension monitoring and the "standard for coherence" on the construction of a situation model. The latter turns out to be lower than assumed. However, this may also be related to the merely average reliability of the measurement tool developed for the study and would have to be re-examined in a further investigation. Still, there is an influence of both variables. For instance, children who monitor their reading process less and tend to read texts word by word rather than looking at the text as a whole are less successful in building up a situation model even regarding mathematical word problems. A low standard for building a mental coherence structure, therefore, also plays a role in solving word problems.

The results of the study demonstrate that especially higher-order processes of inference making and metacognition have an effect on the construction of a situation model and thus on the solution process. Competence in word reading, on the other hand, only indirectly affects the situation model via the ability to draw inferences. In the model, the situation model also affects mathematical reading competence: Only when a situation model has been built are adequate solution strategies applied instead of relying on substitute strategies, such as focusing on numbers without considering the context.

Overall, it can be stated that the processes of understanding non-mathematical texts and mathematical word problems are comparable. Influencing factors that play a role in reading texts and have been examined in detail in this study are also relevant for dealing with word problems. Inadequate strategies, in which the situation model is omitted, such as in the case of the direct translation strategy, might be a student's attempt to handle the lack of understanding of a task text. This indicates that reading promotion must also play a part in mathematics lessons. Language classes can do this only to a limited extent since word problems are a subject-specific genre with its specific characteristics. Accordingly, Leiss et al. (2010) refer to mathematical reading competence and explicitly demand its promotion in mathematics lessons. The results of the present study can provide starting points for such support, suggesting that the promotion of reading in mathematics lessons should start with processes of inference making. Particularly with mathematical word problems, the establishment of references on a local and global level is essential. For example, underlining keywords is not helpful if references cannot be established at all. Therefore, support should include, for instance, exercises for making references in mathematical texts. In this study prior knowledge was controlled for, so no conclusion can be made about its influence. Nevertheless, it seems to be reasonable to put word problems in mathematics lessons in a common thematic context and to build up the necessary prior knowledge and vocabulary before working on the actual task. A stronger focus on comprehension monitoring should also be part of the teaching of mathematics, for example, by detecting inconsistencies in task texts. Further studies must examine to what extent such methods are effective and whether they particularly support students with reading difficulties in solving word problems.

As expected, the observed relationships do not differ substantially between L1 and L2 learners. The ability to draw inferences and the underlying processes, as well as standard for coherence or comprehension monitoring, are language independent. Nonetheless, individual difficulties of some children in this particular area may still be due to low basic reading skills, limited vocabulary, or unfamiliarity with certain connectives. However, this can affect L1 learners as well as L2 learners. Support targeting inference skills should therefore be effective for all students regardless of their first language.

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