Title

The Relation of Teaching Quality to the Task Difficulty in Word Problems

Running title

Word problems: Difficulty and Teaching Quality

Keywords

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Abstract

The ability to solve various types of word problems is an important prerequisite in general problem-solving skills and a central topic in mathematics curriculum. It has been shown that the difficulty of word problems arises from characteristics of the problems themselves (e.g., arithmetic and linguistic characteristics), the solver, and the environment. Yet, little is known about how teaching quality influences the successful solution of different types of word problems. This study examines the relation between student-perceived teaching quality and word problem solving performance in a sample of 387 5th and 6th grade students by independently manipulating the linguistic (lexical consistency and nominalization) and arithmetic (operation and carry/borrow) complexity. Multilevel analysis showed that teaching quality influenced word problem performance. In the face of nominalization, it also indicates that teachers' frequency of activating cognitive processes and a supportive climate increased students' solution accuracy of problems with greater reading difficulty. These results provide evidence that teaching quality has a differential impact on performance in different types of word problems.

Keywords: word problem, individual capability, arithmetic operation, nominalization, consistency, carry, teaching quality

Introduction

Solving word problems (WPs) is an essential part of the educational goals of mathematics curricula around the world (Stacey, 2005) as a means to develop general problem-solving skills. Good problem-solving skills are a strong positive predictor of young adult ability to participate in post-secondary education. However, the goal of many curricula – to teach complex problem-solving abilities – cannot be met because students experience severe difficulty with simple arithmetic WPs (OECD, 2013).

The difficulties with simple WPs originate from various sources. First, both **linguistic and arithmetic factors** (i.e., task characteristics) influence the accuracy (ACC) of a solution (e.g., Daroczy, Meurers, Heller, Wolska, & Nürk, 2020). Second, depending on **individual characteristics** – language abilities, mathematical abilities, intelligence, socioeconomic status – which are differentially associated with performance (e.g., Walkington, Clinton, & Shivraj, 2018). Nevertheless, task characteristics and individual characteristics are not the only relevant factors; failures might originate from various sources (Ulu, Tertemiz, & Peker, 2016). Third, several studies indicate that the **environment** influences how students solve WPs of differing complexity and that the way WPs are taught in the classroom may influence performance (Carraher, Carraher, & Schliemann, 1985; De Corte & Verschaffel, 1987; Lean, Clements, & Del Campo, 1990). Teaching method and quality of instruction are critical for proper learning and play an important role in academic performance in general (Greer, 1997; Thatcher, Fletcher, & Decker, 2008). Moreover, teacher behavior has both a direct and an indirect effect on mathematical achievement (Nortvedt, Gustafsson, & Lehre, 2016) and problem solving ability (Pimta, Tayraukham, & Nuangchalerm, 2009). The teaching quality (Lipowsky et al., 2009) is an especially powerful predictor of student mathematical performance (Kunter et al., 2013; Leon, Medina-Garrido, & Núñez, 2017; Morin, Marsh, Nagengast, & Scalas, 2014) and student

learning (Kersting, Givvin, Thompson, Santagata, & Stigler, 2012). Nevertheless, very little is known about the link between teaching quality (Klieme, Pauli, & Reusser, 2009) and WP solving performance, especially when differentiating between the various types of WPs.

When trying to understand the links between teaching quality and various types of WPs, it is important to understand what quality of teaching would better foster success in solving which type of WP. For instance, are linguistically and/or mathematically different WPs fostered by different teaching styles? Therefore, this study aims to investigate whether teaching quality has a differential impact on performance in different types of WPs while controlling for various task characteristics in an independent manner. To the best of our knowledge, this paper is the first to systematically manipulate both the linguistic and the mathematical properties of WPs and consider them with teaching quality.

Teaching Quality

Nevertheless, previous evidence on how teaching quality affects WP performance is scarce. In this study, we expect that better teaching quality leads to greater solution ACC. Teaching quality according to (Klieme et al., 2009) comprises three components: cognitive activation, supportive climate, and structured classroom management. The first component, *cognitive activation*, integrates challenging tasks, the exploration of concepts, ideas, and prior knowledge (Lipowsky et al., 2009). In classrooms that encourage cognitive activation, we hypothesize that teachers use tasks which challenge students to create mental models for the WPs which would thus lead to better performance. The second component of teaching quality, *classroom management*, focuses on classroom rules and procedures, coping with disruptions, and smooth transitions (Fauth, Decristan, Rieser, Klieme, & Büttner, 2014; Seidel & Shavelson, 2007). For instance, classroom organization, support offered to students, and how solving WPs is explained has a great impact on learning (Titsworth, McKenna, Mazer, & Quinlan, 2013).

Student achievement in general is affected by classroom management because classrooms that experience few disruptions, (i.e., classrooms with good classroom management) thus providing an environment where students are better able to concentrate on their tasks, are expected to be associated with greater WP solution ACC. The third component of teaching quality, *supportive climate*, covers “specific aspects of the teacher-student relationship, such as positive and constructive teacher feedback, a positive approach to student errors and misconceptions, and caring teacher behavior” (Fauth et al., 2014). Classrooms with a positive and supportive climate generally enhance student performance (Hugerat, 2016). Therefore, this component of teaching quality should have a positive impact on WP performance in this study because when students working with text problems are better supported and instructed by their teachers, they are likely to be better equipped to deal with difficulties. A supportive climate may also reduce anxiety related to WP solving, as it has been shown that perceptions of classroom communication climate directly influence student state motivation, which has a direct impact on math anxiety (Lin, Durbin, & Rancer, 2017). It is well known that mathematics anxiety is also directly related to performance (Kyttälä & Björn, 2014), therefore we would expect to see an effect of supportive climate on performance.

In sum, teaching quality should influence WP solving performance independently from problem type and difficulty. At the same time, one can also expect some interactive effects: teaching quality can differentially affect different WPs depending on their arithmetic and linguistic structure. This can be systematically tested when one manipulates these factors independently.

Teaching Quality and Task Characteristics

Task Characteristics affect WP solving. For instance, (Daroczy et al., 2020) showed main effects of both linguistic and arithmetic factors on WP solving time and accuracy in adults. It seems that the same effects can also be observed in children (Daroczy, Artemenko, Meurers, Wolska, & Nuerk, 2020, November 13); the results could be partially replicated with the same factors, indicating general effects. However, both of these studies were conducted in a lab setting, but not in an ecologically valid setting. The studies also do not answer and address the question regarding the role of the quality of teaching. Depending on how arithmetic and linguistic factors of the WPs are manipulated, the underlying mathematical problem, as well as the solver-built mental model, can remain unchanged (i.e., isomorphic problems) or change (i.e., non-isomorphic problems).

Isomorphic Problems. It is possible to manipulate the mathematical difficulty of the problem while keeping the text of the problem constant (Davis-Dorsey, Ross, & Morrison, 1991; Staub & Reusser, 1992; Stern & Lehrndorfer, 1992; Thevenot & Barrouillet, 2015; Vicente, Orrantia, & Verschaffel, 2007). Carry/borrow is such an arithmetic factor. The presence of *carry/borrow* influences the difficulty of calculation but does not change the underlying mathematical structure of a WP. Moreover, the text of the problem remains unchanged. In line with previous research (e.g., Daroczy et al., 2020), we expect that presence of carry/borrow will affect WP solving performance; accuracy of problems requiring carry or borrow (e.g., $19 + 9 = ?$, $25 - 9 = ?$) will be lower compared to problems, which do not require it (e.g., $11 + 12 = ?$, $15 - 12 = ?$).

We expect also that teaching quality will affect solution ACC in a positive way. Several studies have shown that children have lower ACC when computing the solution to a sum for which adding the units leads to a change in the number of tens (e.g., $14 + 9 = 23$) (Deschuyteneer, De Rammelaere, & Fias, 2005; Furst & Hitch, 2000) than when it does not

(e.g., $11 + 12 = 23$). At the same time, numeracy of children is influenced by teachers, and linked to mathematical achievement (Tozer & Holmes, 2005). Therefore, teaching quality should increase performance on WPs. We expect the teaching quality classroom management to play an especially critical role because children who are already out of elementary school should know the strategies (Fuchs et al., 2010), but a better managed classroom can foster better concentration in the classrooms, which automatically leads to better solution rates (Oliver, Wehby, & Reschly, 2011).

Even simple changes to the text can enhance performance (e.g., Walkington et al., 2018). **Nominalization** is a linguistic factor that influences reading difficulty but does not change the underlying mathematical structure of a WP. Nominalization refers to changing verbs into nouns; for instance, a noun “the selling” is being used instead of the verb “to sell” (Gibson & Warren, 2004; Halliday & Matthiessen, 2004). Similar to the borrow/carry factor, nominalization of WPs has not yet been linked with teaching quality. We would expect that nominalized forms of WPs may be more difficult for children to solve, as nominalization also influences the solving process in WPs (Daroczy et al., 2020; Prediger, Wilhelm, Büchter, Gürsoy, & Benholz, 2015). For adults, it took longer to solve sentences with the nominalized form but did not influence the solution ACC (Daroczy et al., 2020). For children, it not only took longer to solve sentences with the nominalized form compared to the verbalized form, but when sentences included the nominalized form, a reduced ACC could be observed in sentences with subtraction compared to addition and in sentences with lexically inconsistent form compared to sentences with lexically consistent form (Daroczy et al., 2020, November 13).

Dealing with nominalization is also closely linked with reading comprehension skills, which is a key ability in understanding and solving mathematical problems. For instance, if the text of a problem uses the nominalized form, the reading comprehension demand may increase

(Fang, 2006). Moreover, there is a strong link between reading and mathematics outcomes, not only at the individual level, but also at the classroom level (Adelson, Dickinson, & Cunningham, 2015). In particular, classroom management (one of teaching quality components) was found to be a strong predictor for reading comprehension skills (Antoniou & Sideridis, 2008; Garwood, Vernon-Feagans, & Investigators, 2017). Therefore, we would expect classroom management to decrease the nominalization effect. Supportive climate could work similarly to classroom management; however, the evidence is sparse. Demir (2018) also indicated that the teaching quality components cognitive activation and classroom management increased students' mathematical problem-solving ability. Finally, there is a significant positive correlation between instructional quality and mathematics observed in several, but not all, educational systems (Nortvedt et al., 2016).

Non-Isomorphic Problems. In non-isomorphic problems, the manipulation of a linguistic or mathematical factor changes the underlying mathematical structure.

For example, ***arithmetic operation*** is an arithmetic factor that changes the underlying mathematical structure of a WP and influences problem complexity (Koedinger & Nathan, 2004). As WPs requiring subtraction are harder to solve and reinforce a different strategy (De Corte & Verschaffel, 1987), we expect such problems will be of greater difficulty in the current study as compared to those requiring addition. For adults, it takes longer to solve word problems containing subtraction than addition (Daroczy et al., 2020). For children, it not only takes longer to solve subtraction problems, but in more semantically complex sentences, subtraction problems elicit more errors compared to addition problems (Daroczy et al., 2020, November 13).

Some WPs might contain specific keywords that hint at the solution (e.g., linguistic markers like “less” or “more”). In some cases, this is consistent with the required mathematical

operation and in other cases it is not. This is referred to as *lexical consistency or inconsistency*. Lexical consistency is a linguistic factor that changes the underlying mathematical structure of a WP. Studies have shown that participants, especially children, display longer response times and higher reversal error rates when solving lexically inconsistent problems as compared to consistent problems (Hegarty, Mayer, & Green, 1992; Hegarty, Mayer, & Monk, 1995; Pape, 2003; Van der Schoot, Arkema, Horsley, & van Lieshout, 2009; Verschaffel, De Corte, & Pauwels, 1992). In a study by Daroczy et al. (2020) in adults, lexically inconsistent sentences resulted in overall higher errors rates than lexically consistent sentences in subtraction problems. In children, the consistency effect was found only for more semantically complex sentences (Daroczy et al., 2020, November 13). Therefore, in the current study we expect lower ACC in lexically inconsistent problems.

However, the reduced ACC in both subtraction and inconsistent sentences might be also due to the differences in the quality of teaching and to false assumptions. False assumptions about WPs (e.g., that every problem can be solved with a single operation; Cummins, Kintsch, Reusser, & Weimer, 1988) are sometimes believed and instructed by teachers (Fuentes, 1998; Nortvedt et al., 2016). In particular, an assumption facilitated and even encouraged by teachers is the use of keyword strategies (e.g., Boote & Boote, 2018; Jitendra et al., 2015). Together, these findings indicate that teachers may have some influence over the fact that students pick out numbers and keywords instead of creating mental models (e.g., Hegarty et al., 1995). Of course, such strategies might work for simple problems, but not for more demanding ones. The keyword strategy is especially error-prone when applied to WPs containing lexically inconsistent (where the keyword does not refer to the correct operation) sentences (Hegarty et al., 1992; Hegarty et al., 1995). Therefore, in this study the cognitive activation should be positively correlated with WP success because it encourages problem understanding rather than the use of the keyword strategy. This means in classrooms that encourage cognitive activation,

we would hypothesize that teachers use tasks that challenge students to create mental models. In such classrooms, we expect that the better cognitive activation in particular elicits decreases the inconsistency effect.

In conclusion, it is important to consider teaching quality as a factor since it impacts student performance. Namely, the supportive climate component should reduce anxiety and enhance performance in WP solving, classroom management should affect performance through less distraction and better concentration in the classrooms, and cognitive activation should encourage building better mental models, which are required in WP solving. Additionally, we expect that teaching quality differentially affects the ACC of different WPs. For instance, in the case of nominalization linked through increased reading comprehension and carry/borrow through numeracy skills to classroom management. Finally, the factors lexical inconsistency and operation should be especially affected by cognitive activation due to the increased mental load.

Research questions and hypotheses

The theoretical insights outlined above lead to the following research question: How does environment work with linguistic and arithmetic difficulty to influence WP solution ACC? We expect a positive relationship between teaching quality scales and more arithmetically and linguistically demanding items (cognitive activation in particular should increase ACC on lexically inconsistent items).

Methods

Participants

The participants were 387 (Age $M=10;7$, $SD=0.70$) students from nine schools, 25 classes (gymnasiums) in the state of Baden-Württemberg, Germany (students/class $M=16.32$, $SD=4.82$). All participants were between 10 and 13 years of age (5th and 6th graders); 193 girls

and 191 boys, three participants did not report their gender. Neurological or psychological disorders were exclusion criteria. Participation was on a voluntary basis.

Stimuli and Design

The study was a 2x2x2x2 within subject and orthogonal design with the main four factors: operation (addition vs. subtraction), carry/borrow (carry/borrow vs. non-carry/non-borrow), consistency (consistent vs. inconsistent form), nominalization (verbalized vs. nominalized form). Each of the 16 conditions consisted of 3 sentences, resulting in 48 total WPs (see Supplementary Material 1). The WPs were a chosen subset, as in the paper (Daroczy et al., 2020).

There was a 15-minute time limit to solve all 48 of the WPs. The problems were divided into three blocks of 16 tasks. Each block consisted of all conditions. Task order was pseudorandomized within each block in order to avoid presenting the same order of WPs to participants sitting next to each other to discourage cheating.

Teaching quality

Teaching quality was assessed via student ratings based on the model of Klieme et al. (2009), where teaching quality is comprised of three basic dimensions: supportive climate, effective classroom management, and cognitive activation (Fauth et al., 2014; Sandilos, Rimm-Kaufman, & Cohen, 2017). Student ratings were used to make a correlation between WP performance and teaching quality. Additionally, we measured the correlation between student perception of the classroom environment, solving WPs, and various other cognitive variables, such as motivation. Items for classroom management assessment were taken from Fauth et al. (2014). The questionnaire included 21 items on three sub scales: supportive climate (nine items), classroom management (five items), and cognitive activation (seven items). All items were rated on a four-

point scale ranging from strongly disagree to strongly agree (Table 1.). For all three scales we used the mean value of the responses (scale of 0 to 4) in the analysis.

Noteworthy, student ratings seem to be a valid measure of teaching quality (Fauth et al., 2014; Sandilos et al., 2017). A student's view of their classroom reflects the actual characteristics of the classroom experience (Brock, Nishida, Chiong, Grimm, & Rimm-Kaufman, 2008; Howard, 2001). Moreover, results from Sandilos et al. (2017) indicated that student perceptions of teacher demands (challenge and control) are related to mathematical achievement.

insert Table 1

Individual Variables. As individual variables can partial out the relationship between teaching quality and performance, we added some individual variables to the analysis as control variables. The results and the detailed discussion can be found alongside the description of the tests in the Supplementary Material 2.

Results

Analysis

An effect-based analysis was conducted to investigate the association between environmental factors, individual abilities, and task characteristics. ACC across conditions are shown in the Supplementary Material 3; ACC results were arcsine-square-root-transformed prior to analysis to approximate a normal distribution (see Winer, Brown, & Michels, 1971). Raw means and standard deviations are shown in Table 2.

insert Table 2

First, we calculated the intraclass correlation coefficients (ICCs; see Table 3) to define the proportion of total variance that could be attributed to between class differences. ICC(1) is the index of the average agreement between pairs of students within the same class, whereas ICC(2) refers to the reliability of the group average (Marsh et al., 2012). In the case of student ratings, ICC(1) can be seen as the degree to which student ratings of classroom features are affected by being in different classes (Lüdtke, Robitzsch, Trautwein, & Kunter, 2009). In multilevel studies, ICC(1)s for climate variables are often less than .10 and rarely greater than .30 (e.g., Marsh, Martin, & Cheng, 2008).

insert Table 3

For the *effect-based analysis* we used the first two WP blocks (B1+B2) containing 32 problems. The reason is that including only the first block (B1) in the effect-based analysis would not have provided enough variance. Additionally, only approximately the best 1/3rd of the students could solve all the three blocks within the given time. Therefore, we used the first two blocks (B1+B2). Participants who had missed more than 3 continuous items and those for whom more than 20 % of the data was missing were excluded from the analysis blocks. These restriction criteria were necessary to be able to compute the effects. With these restrictions, 273 (age $M=11;7$, $SD=0.74$) students from 23 classes (students/class $M=11.70$, $SD=4.37$) were included in the effect-based analysis: 141 girls (age $M=11;7$, $SD=0.68$) and 132 boys (age $M=11;7$, $SD=0.84$). Difference scores in ACC were generated between the following:

inconsistent tasks and consistent tasks (*consistency effect*); nominalized tasks and verbalized tasks (*nominalization effect*); subtraction tasks and addition tasks (*operation effect*); carry/borrow tasks and non-carry/non-borrow tasks (*carry/borrow effect*). These effects can be interpreted similarly, taking for example nominalization: a positive value for the nominalization effect means that participants experience more failure in nominalized tasks, and higher values indicate more errors due to the difficulty of the nominalization. The difference between effect scores reflects differences in performance on the different WPs. In the effect-based analysis, ICC(1) values indicated that 2% and 5% of the total variance may have been due to classroom differences for the *nominalization effect* and the *carry/borrow effect*, respectively. ICC(1) values for the *operation effect* and *consistency effect* were negative or zero. This means that there was no level 2 variability in the outcomes when accounting for classroom membership; therefore, we did not conduct the multilevel analysis. In the nominalization and carry/borrow effect models, students (level 1; L1) were nested in classrooms (level 2; L2). Clustering at the classroom level was handled by the TYPE = TWOLEVEL option in Mplus. In this way, we examined four models each for nominalization and the carry/borrow effect. The basic dimensions of teaching quality were included separately (*Models 1-3*) as well as together (*Model 4*) as an L2 predictor. Additionally, individual variables were entered as a L1 predictors in each of the models.

Effect Based Analysis

Nominalization effect. In *Model 1*, supportive climate accounted for 63% of the L2 variance. In *Model 2*, cognitive activation accounted for 96% of the L2 variance. In *Model 3*, intelligence, reading comprehension, and self-concept were significant predictors at L1 and accounted for 6% of the variance. In *Model 4*, cognitive activation and supportive climate ($p < 0.1$) together

accounted for 97 % of the L2 variance (see Table 4). Intelligence, reading comprehension, and self-concept were significant predictors at L1 in each of the models, and accounted for 6% of the variance. The effects of nominalization were smaller with higher intelligence and reading comprehension, and mathematics self-concept magnified the effect of nominalization.

insert Table 4

Carry/borrow effect. There were no predictors found at L2 (see Table 5). Intelligence was a significant L1 predictor.

insert Table 5

In sum, 15% of the differences in total ACC, as well as 5% of the nominalization and 2% of the carry/borrow effects, can be explained by classroom differences. *The effect-based analysis* revealed that, for the carry/borrow effect, there was no significant L2 predictor, and only intelligence turned out to be a significant L1 predictor. The nominalization effect had less of an impact when students rated supportive climate and cognitive activation highly. Finally, L1 predictors such as high intelligence and reading comprehension also accounted for better results in the face of nominalization.

Discussion

This study investigated whether teaching quality has a differential impact on the performance in different types of WPs. Substantively, we were able to confirm cognitive activation to be

predictive of performance when WPs are presented in an isomorphic linguistically more complex nominalized form. The result indicated that teachers' frequency of activating cognitive processes and a supportive climate increased students' solution ACC of problems requiring greater reading skills. In general, the hypothesis that teaching quality affects solution ACC on arithmetically and linguistically complex items was only partially confirmed. Namely, we found no evidence that the teaching quality plays a role in the case of the lexical consistency effect, the carry/borrow effect, or the operation effect, but rather only in the case of the nominalization effect. For these factors, it seems that there is little to no difference between classrooms. Finally, the results of the accuracy measures results are in line with our previous studies (Daroczy et al., 2020, November 13; Daroczy et al., 2020). For adults in the study of Daroczy et al. (2020), the manipulation of carry/borrow and the factor inconsistency resulted in significantly lower accuracy. In addition to that, Daroczy et al. (2020, November 13) showed that for children the consistency and the operation effect is only present in sentences with higher semantic complexity. That is, in sentences with the nominalized form, but not in sentences with the verbalized form. In the current study, the results of the ACC hint to the generalizability of these effects, as all the linguistics and arithmetic factors showed a significant main effect.

Nominalization effect. While entering teaching quality scales one by one in the models, supportive climate and cognitive activation reduced the effect of nominalization. However, in the model where all teaching quality scales were included, only cognitive activation alone reduced the effect of nominalization. This indicates that students from classrooms with better cognitive activation can solve linguistically demanding tasks. As denser nominalization generally results in lower solution ACC (Prediger et al., 2015), our results support the finding that high quality instruction might weaken the relationship between reading comprehension and mathematical achievement (Adelson et al., 2015). On the other hand, the hypothesis that classroom management plays a bigger role in reducing the nominalization effect compared to

other teaching quality scales could not be confirmed. This can be interpreted as in the case of classroom management, it seems that there is little difference between the classes. The connection between nominalization and cognitive activation could be that mathematical WPs may demand more cognitively advanced reading strategies. Training students in comprehension strategies for reading mathematical WPs helped students to become more successful problem solvers (Graeber, Newton, & Chambliss, 2012). In addition, cognitive activation seems to have an added effect over the reading comprehension skills because, along with cognitive activation, reading comprehension also accounted for a reduction in the nominalization effect. This indicates good reading competencies (several studies (e.g., Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016; Mullis, Martin, & Foy, 2011) have shown that reading skill directly influenced the solving of WPs) does not aid problem-solving alone, especially if the linguistic part of the WP is difficult. The method of teaching matters. Similarly, although socioeconomic status (SES) has been related to language development in childhood (Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017) and associated with better language abilities (Calvo & Bialystok, 2014)– and in this study SES status led also to a better ACC on the linguistically more demanding WPs – cognitive activation still plays a role while controlling for SES. Finally, there is previous research suggesting a direct relationship between intelligence and WP solving (Mori & Okamoto, 2017; Swanson & Beebe-Frankenberger, 2004). In this study, greater intelligence accounted for higher ACC in the face of the nominalization effect, which indicates that children of higher intelligence made fewer errors when solving problems with nominalization. However, some variance could be explained by the differences between the classrooms, and individual differences are not the only predictors for children’s performance on word problem solving.

Carry/Borrow Effect, Operation Effect and Lexical Consistency Effect. In the case of the carry/borrow effect, there was no significant teaching quality scale predictor, which indicates that classes did not differ in regard to the carry/borrow effect. In addition, contrary to

expectations, we found no differences between classrooms in teaching quality for either lexical consistency or operation. This means that there was no between classroom variation for lexical consistency and operation. Although we did not specifically assess how the teachers taught WPs and to what extent their teaching material contained inconsistent examples, this result indicates that solving WPs with carry/borrow, addition/subtraction, or with consistent/inconsistent forms might be taught similarly across different classrooms. In the case of carry, individual differences – fluid intelligence – mattered more than differences in the classroom. One reason might be that carry/borrow is very easy for that age group, and at that age, teaching quality connected through numeracy skills is no longer a differentiator in performance. Further, the instruction about carry/borrow is given in primary school rather than in high school. In the 5th and 6th grade there is also the transfer from primary school to high school, which means that classes are newly mixed, and students with different backgrounds and previous teaching methods could be attending the same classes.

Teaching Quality

In sum, we hypothesized that all teaching quality scales will have some effect on the performance. Cognitive activation could be related to reading comprehension and calculation skills, supporting the creation of mental models and fostering more strategies; supportive climate through constructive feedback should increase motivation and reduce anxiety; better classroom management should enable better concentration while having less disruptions. However, this was not supported by our results. One possible reason might be that there are floor and ceiling effects. The general performance of the students was good, and in the effect-based analysis only the better children were included in order to compute the effects.

Cognitive Activation was a predictor only in the case of nominalization but not in the other cases. However, higher cognitive activation should have led to better results in lexical consistency and operation, as it would enhance the creation of the correct mental model. One

explanation might be that these tasks are were very easy for the students. The ACC was lowest in the case of lexical inconsistency (86.35 %), followed by carry/borrow (86.95 %), subtraction (86.95 %), and nominalized form (87.94 %), and these tasks were not cognitively demanding enough.

Supportive Climate was a predictor when it was entered in the model alone for the case of nominalization. In this study, the result is not clear and straightforward, as suggested by the study of (Hugerat, 2016), in which supportive climate generally enhances student performance. However, this result is supported by the findings that supportive climate in particular has been found to predict students' motivation (e.g., Ryan & Deci, 2000) and subject related interest (Fauth et al., 2014), but not the performance directly. Indeed, motivation was correlated with supportive climate in this study. This is in line with the study of Leroy, Bressoux, Sarrazin, and Trouilloud (2007), where supportive climate was associated with higher motivation.

Classroom management was not a predictor in any models. The explanation for this might be that classroom management would not be the first indicator to predict effect-based results that are a very specific indicator of student ability to cope with difficult text in WPs. This means that this component of teaching quality is not that important when compared to the other components. This indicates that whether students are able to deal with complex WPs likely depends more on the way mathematics is instructed in their classroom and if proper support is offered during the learning process rather than on the general level of classroom management. Nevertheless, our results show that aggregated classroom management value correlated positively with total performance. Student ratings also indicated an overall highly perceived classroom management.

Limitation

However, some limitations should be noted. First, additional linguistic and cognitive factors play a role. For instance, emotional factors such as anxiety, which haven't been measured in

this study, have been shown to play a considerable role in WP performance (Passolunghi, Cargnelutti, & Pellizzoni, 2019). Additionally, a connection to individual interests might increase solution ACC, and a supportive climate might reduce anxiety. In this paper we investigated factors which were either linguistically/numerically isomorphic or non-isomorphic (i.e., manipulating the factor does or does not change the underlying mathematical structure); however, we did not consider a factor which does not change the underlying structure but manipulates the calculation process, such as a linguistic change. For example, Bassok, Chase, and Martin (1998) have shown that in WPs, additions are easier when people have to add up functionally connected words (e.g., bird-cages) than categorically connected words (e.g., tulips, daisies). Second, the reason why some of the teaching quality scales did not turn out as predictors is that all participating school type belongs to the type “*Gymnasium*” (i.e., high school) where the children with higher socioeconomic status and overall cognitive abilities attend; thus, the performance on the word problems were high.

Implications

The educational implications of these findings are relevant to the research and have a bearing on practical issues. Our results show that performance does not only depend on reading comprehension, mathematical skills, and intelligence, but partially also on how supportive the environment is. Our finding that cognitive activation and supportive climate reduced the nominalization effect means that, for instance, positive and constructive teacher feedback, a positive approach to errors and misconceptions, the integration of challenging tasks and the exploration of concepts and ideas help to achieve better results with linguistically complex WPs. This is important because Nortvedt et al. (2016) showed that only 12 % of teachers offered high quality instruction in both reading and mathematics, and German schools offer little cognitive activation for mathematical problem solving (Neubrand, Jordan, Krauss, Blum, & Löwen, 2013), despite the fact that mathematical texts are claimed to require special literacy

skills (e.g., Burton and Morgan (2000) or Österholm and Bergqvist (2012)). Recent findings argue for the importance of drawing student attention not only to the mathematical aspects but also to the linguistic aspects of WPs (Fuchs, Gilbert, Fuchs, Seethaler, & Martin, 2018; Kyttälä & Björn, 2014). This suggests that closer attention should be paid to linking teaching quality with various types of WPs in order to understand what characteristics of teachers would better foster which type of WP solving success. Moreover, a practical implication would be the possibility to design/build the WPs to fit the needs of the children and educators. While disconnecting the linguistics factors from the mathematical factors – or mixing them together – we can design the word problem to fit the educational purpose and vary the difficulty depending on the educational objective. For example, if the linguistic difficulty is disturbing, the text can be simplified, but maybe – such as for a more advanced student in a different classroom – the goal is to have a linguistically more complex text.

Summary

This article presents assessments of WP solving in relation to individual abilities and teaching quality. The goal of this study was to investigate how teaching quality (classroom management, cognitive activation, and supportive climate) affects WP solution ACC while distinguishing between arithmetically and linguistically simple and complex WPs. The analysis revealed that that teachers' frequency of activating cognitive processes and a supportive climate increased students' solution ACC of problems with greater reading difficulty skill. Theoretically, our results provide evidence that, besides the importance of individual factors, cognitive activation especially affects performance on linguistically demanding WPs.

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Compliance with Ethical Standards

Informed consent was signed by all participants. The study was performed in accordance with the ethical standards of the Declaration of Helsinki. Disclosure of potential conflicts of interest: The authors declare that there is no conflict of interest.

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Table 1

Teaching Quality Scales

Scales	Items
Classroom management	<p>In our science class ...</p> <p>none of the students disturb the lesson</p> <p>students are quiet when the teacher speaks</p> <p>everybody listens, and students are quiet</p> <p>nobody interrupts with talking</p> <p>everybody follows the teacher</p>
Cognitive activation	<p>In our science class ...</p> <p>we are working on tasks that I have to think about very thoroughly</p> <p>Our science teacher ...</p> <p>asks me what I have understood and what I haven't</p> <p>asks questions that I have to think about very thoroughly</p> <p>gives us tasks that seem to be difficult at a first glance</p> <p>asks what we know about a new topic</p> <p>gives us tasks I like to think about</p> <p>wants me to be able to explain my answers</p>
Supportive climate	

Our science teacher ...

is nice to me even when I make a mistake

cares about me

encourages me when I find a task difficult

tells me how to do better when I make a mistake

likes me

tells me what I'm already good at and what I still have to learn

is friendly to me compliments me when I did something good

believes that I can solve difficult tasks

Table 2

Descriptive Data (raw means, SD, Median, Skewness)

	Total Sample N=359				Restricted Sample N=279			
	Mean	SD	Median	Skewness	Mean	SD	Median	Skewness
Demographic Data								
Age	10.86	0.71	11	0.17	10.92	0.71	11	0.17
Classroom Measures L1								
Cognitive Activation L1	2.85	0.53	2.8	-0.5	2.82	0.55	2.8	-0.5
Classroom Management L1	2.24	0.66	2.17	-0.11	2.26	0.64	2.2	-0.17
Supportive Climate L1	3.28	0.56	3.44	-1.25	3.28	0.57	3.44	-1.37
Classroom Measures L2								
Cognitive Activation L2	2.85	0.19	2.92	-0.67	2.84	0.2	2.89	-0.54
Classroom Management L2	2.24	0.33	2.35	0.06	2.26	0.34	2.35	0
Supportive Climate L2	3.28	0.23	3.32	-0.67	3.28	0.23	3.3	-0.6
Performance Measures								
Total Accuracy (percentage)	0.77	0.19	0.77	-0.47	0.84	0.13	0.85	-0.26
Accuracy B1+B2 (percentage)	0.82	0.16	0.88	-1.31	0.89	0.09	0.91	-0.98
Linguistics Effects								

Nominalization Effect	-0.34	1.72	0	0.09	-0.37	1.65	0	-0.02
Consistency Effect	-0.82	1.96	-1	-0.32	-0.81	1.7	-1	-0.33
Mathematical Effects								
Carry Effect	-0.91	2.1	-1	-0.99	-0.7	1.84	0	-0.89
Operation Effect	-0.7	2.02	-1	-0.17	-0.63	1.84	-1	-0.04

Note: L1 refers to Individual Level, L2 Refers to Classroom Level, B1 to Block 1, B2 to Block 2

Table 3

ICC(1) & ICC(2) values

	Total Sample N=359		Restricted Sample N=279	
	ICC(1)	ICC(2)	ICC(1)	ICC(2)
Classroom Measures L1				
Cognitive Activation L1	0.07	0.54	0.08	0.52
Classroom Management L1	0.21	0.80	0.24	0.78
Supportive Climate L1	0.11	0.64	0.10	0.58
Motivation: Self-Concept	0.06	0.48	0.11	0.59
Performance Measures				
Total Accuracy	0.15	0.72	0.03	0.26
Linguistics Effects				
Nominalization Effect	-	-	0.05	0.38
Consistency Effect	-	-	0.00	-0.01
Mathematical Effects				
Carry/Borrow effect	-	-	0.02	0.23
Operation Effect	-	-	-0.03	-0.62

Table 4

Nominalization Effect.

	Model 1	Model 2	Model 3	Model 4
Individual Level				
Intelligence	-0.09 (0.03)*	-0.09 (0.03)*	-0.09 (0.03)*	-0.09 (0.03)*
Reading Speed	0.04 (0.04)	0.04 (0.04)	0.04 (0.04)	0.04 (0.04)
Reading Comprehension	-0.09 (0.04)*	-0.09 (0.04)*	-0.09 (0.04)*	-0.09 (0.04)*
Visual Span	0.05 (0.03)	0.05 (0.03)	0.05 (0.03)	0.05 (0.03)
Verbal Span	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)
Interest	-0.07 (0.06)	-0.07 (0.06)	-0.07 (0.06)	-0.07 (0.06)
Individual Importance	-0.02 (0.08)	-0.02 (0.08)	-0.02 (0.08)	-0.02 (0.08)
Selfconcept	0.14 (0.06)*	0.14 (0.06)*	0.14 (0.06)*	0.14 (0.06)*
Socio-economic Status	0.05 (0.04)	0.05 (0.04)	0.05 (0.04)	0.05 (0.04)
Mathematic	0.04 (0.04)	0.04 (0.04)	0.04 (0.04)	0.04 (0.04)
Classroom Level				
Supportive Climate	-0.07 (0.04)*			-0.05 (0.03)
Cognitive Activation		-0.11 (0.02)*		-0.08 (0.03)*
Classroom Management			0.04 (0.03)	0.04 (0.03)
R ² within	0.07	0.07	0.07	0.07
R ² between	0.92	0.93	0.95	0.95

* two-tailed significant, Supportive Climate $p < 0.1$

The basic dimensions of teaching quality were included separately (Models 1-3) as well as together (Model 4) as an L2 predictor.

Table 5

Carry/borrow effect.

	Model 1	Model 2	Model 3	Model 4
Individual Level				
Intelligence	0.08 (0.04)*	0.08 (0.04)*	0.08 (0.04)*	0.08 (0.04)*
Reading Speed	0.01 (0.03)	0.01 (0.03)	0.01 (0.03)	0.01 (0.03)
Reading Comprehension	-0.02 (0.03)	-0.02 (0.03)	-0.02 (0.03)	-0.02 (0.03)
Visual Span	-0.02 (0.05)	-0.02 (0.05)	-0.02 (0.05)	-0.02 (0.05)
Verbal Span	-0.04 (0.04)	-0.04 (0.04)	-0.04 (0.04)	-0.04 (0.04)
Interest	-0.02 (0.06)	-0.02 (0.06)	-0.02 (0.06)	-0.02 (0.06)
Individual Importance	0.09 (0.08)	0.09 (0.08)	0.09 (0.08)	0.09 (0.08)
Selfconcept	-0.05 (0.04)	-0.05 (0.04)	-0.05 (0.04)	-0.05 (0.04)
Socio-economic Status	-0.04 (0.04)	-0.04 (0.04)	-0.04 (0.04)	-0.04 (0.04)
Mathematic	0.05 (0.05)	0.05 (0.05)	0.05 (0.05)	0.05 (0.05)
Classroom Level				
Supportive Climate	0.00 (0.04)			-0.04 (0.05)
Cognitive Activation		-0.01 (0.04)		0.02 (0.05)
Classroom Management			0.07 (0.04)	0.08 (0.04)
R ² within	0.05	0.05	0.05	0.05
R ² between	0.02	0.01	0.17	0.38

*The basic dimensions of teaching quality were included separately (Models 1-3)**as well as together (Model 4) as an L2 predictor.*