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Do connectives improve the level of understandability in mathematical reality-based tasks?

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ABSTRACT

Previous studies suggest that sentence-linking elements, like connectives, enhance text comprehension since they help produce a context of meaning. However, there is no evidence yet on whether connectives influence the understanding and solving of reality-based mathematical tasks. In this study, reality-based tasks were varied to create two versions with identical content, differing only in whether coherence relations were expressed explicitly by connectives or implicitly. The investigation aimed to determine if this variation affected students' ability to comprehend the described situation and solve mathematical tasks based on the provided information. Initial results indicate that connectives do increase the rate of correct answers to comprehension questions, particularly for students with lower linguistic skills. Nevertheless, the use of connectives did not significantly influence mathematical task performance. This suggests that while connectives aid in understanding and organizing information, they may not contribute to students translating this advantage into improved mathematical task outcomes.

Keywords: language and mathematics, modelling tasks, coherence, connectives, comprehension, linguistic features

INTRODUCTION

Previous studies (Kleijn et al., 2019; Köhne-Fuetterer et al., 2021; Sanders & Noordman, 2000) suggest that the use of connectives has a positive effect on comprehension, as they help to understand discourse relations in a text. However, there is no empirical evidence yet on whether and in which way connectives affect the formation of a coherent situation model when it comes to understanding mathematical reality-based tasks. It is also unclear whether certain groups of students may benefit particularly from the use of connectives. Based on previous studies, it can be assumed that students with lower language skills (Becker & Musan, 2014) and readers with little prior knowledge and interest in the topic (Kamalski, 2007) are the ones to benefit most from the explication of coherence relations through connectives. On the other hand, it is also known that connectives can be challenging to understand, especially for non-native speakers, due to their great lexical and structural ambiguity (Crible, 2021; Missing, 2017). These assumptions are also related to the question of whether the linguistic construction of a task may pose difficulties for specific student groups in performance situations.

To find out how connectives affect the understandability and solving of mathematical reality-based tasks, for this study, six reality-based tasks have been varied to create two identical variants, differing only in terms of whether coherence relations are explicitly expressed by connectives or are expressed implicitly. To test which of the two text versions enables 7th to 10th grade students (n = 390) best to form a proper situation model, the students were asked to answer comprehension questions on discourse relations expressed in the text as well as to solve mathematical tasks on the text.

THEORETICAL BACKGROUND

Although students experience significantly greater difficulties in reality-based tasks than in mathematical tasks with low linguistic demands (Leiss et al., 2019; Verschaffel et al., 2000), it is not yet fully understood why these difficulties occur. Prediger (2010) lists different types of challenges in reality-based tasks. These are, on the one hand, basic reading difficulties and secondly, a lack of appropriate mathematical basic ideas, resulting in the selection of the wrong operators. Another important challenge is the creation of an adequate situation model. The situation model (cf. Van Dijk & Kintsch, 1983) does not simply represent the wording of the text but is a mental image of the situation described; with regard to individual aspects, it can be much more comprehensive than what is written. Crucial for the formation of the situation model is that temporal and functional relations, in other words, coherence relations, can be established (Cummins et al., 1988; Kehler, 2022). However, especially lower performing students tend to face difficulties in extracting information from the text and relating it to each other (Schukajlow et al., 2012). This is problematic since understanding the coherence relations of a text does not only lay the foundation for the situation model in the reader's mind but also for all subsequent steps of solving a reality-based task. The individual phases of the solution process can be represented in a modelling cycle, as shown here according to Leiss et al. (2024) (**Figure 1**).

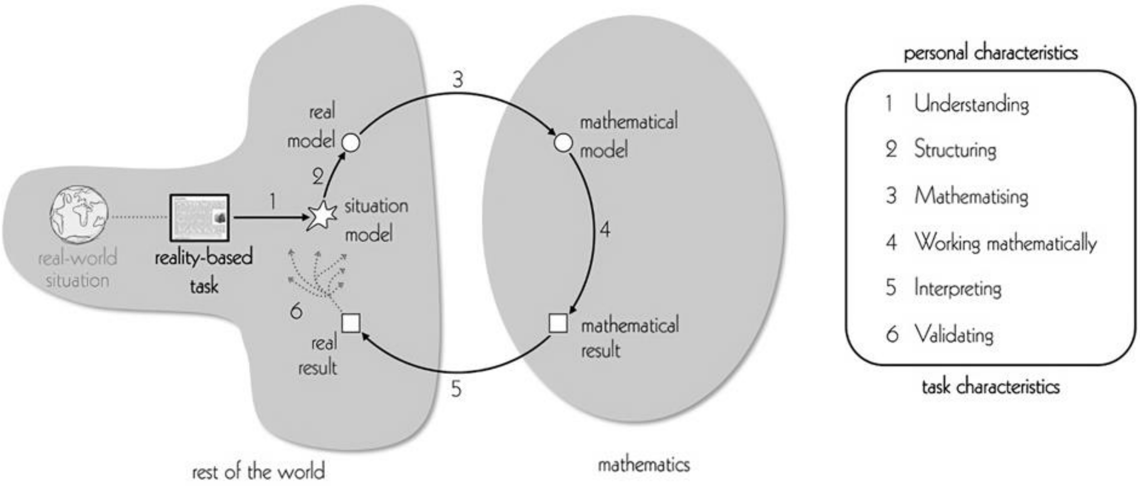

Figure 1. Expanded modelling cycle (based on Blum & Leiss, 2007)

Schukajlow et al. (2012) and Leiss et al. (2019) have shown that the construction of a coherent situation model is crucial for the correct solution of the task and that step 1 in the solution process takes on average about 40 % of the total time needed for the task. Connectives play a crucial role in step 1 and step 2, by contributing to the comprehension and structuring of the task text. Any difficulties encountered here prevent students from identifying and organizing the important information and thus from finding the relevant mathematical details and possible solutions (Rellensmann et al., 2020). That is why we need to understand what supports students in enhancing their understanding of complex coherence relations. One way to help students build a coherent situation model is the use of connectives such as *because*, *but*, and *afterwards* because they provide clues to the reader as to how to link sentences or whole sections of text. They can thus give the reader important information about coherence relations that readers would otherwise have to figure out for themselves. In this way, connectives can be understood as a kind of 'signpost' that gives insight into the intended context of meaning.

Connectives are a very heterogeneous group of linguistic means that can be assigned to different parts of speech. Nevertheless, they all have a common semantic core function: they serve to explicitly express relations in terms of content. Connectives are thus the most important linguistic markers for so-called relational coherence, which establishes a content-related relation between different persons, things, or events; they can interlink parts of sentences, clauses, or even whole sections of text. In this way, they can help readers form an adequate model of the situation described.

However, this does not mean that connectives are mandatory for establishing relational coherence and forming the situation model. As an example, we can look at two variants of the beginning of a reality-based task that is part of this study. One beginning contains connectives while the other does not:

1.
   a. At the airport, travelers go through security control and have to make their way to their gate. From the gate, you board the plane. You should be there on time.
   b. At the airport, travelers first go through security control and then have to make their way to their gate. From the gate, you finally board the plane. Therefore, you should be there on time.

The coherence relations for both examples can be represented schematically, as shown in **Figure 2**.

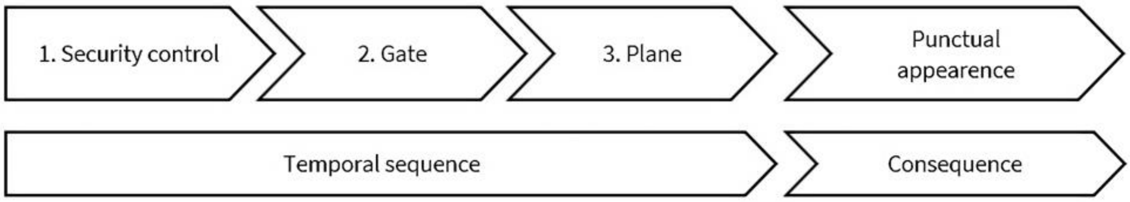

Figure 2. Schematic representation of coherence relations (Source: Authors' own elaboration)

While the first three elements describe the chronological structure of a journey by plane, which includes several steps, the last sentence derives a consequence from this: Since several (time-consuming) steps are necessary before departure, one should be at the airport on time. This intended interpretation is supported in the second variant of the text by the connectives *first*, *then*, *finally*, and *therefore*, which express the coherence relations in a more explicit way. The first variant of the item presents the same procedure and the same consequence, but it names the relations in a less explicit way. Experienced readers can often deduce coherence relations using their prior knowledge and experience. So, although the two texts differ on the linguistic surface, the underlying coherence relations are the same, leading to an identical situation model for experienced readers in both texts. This means that connectives do not automatically lead to a better understanding of the situation described, but they can save the reader time and effort in the search for the right interpretation as studies show that connectives lead to faster processing of what is read (Köhne-Fuetterer et al., 2021; Sanders & Noordman, 2000). Implicitly linked clauses are therefore considered to be more cognitively demanding, as recipients are more dependent on prior knowledge, previously read parts of the text or their own conclusions (Kintsch, 2009; Kleijn et al., 2019). For this reason, connectives are particularly beneficial to comprehension when they clarify relationships between sentences or clauses that could otherwise be misunderstood. In this case, the connective can reduce the recipient's uncertainty (Graesser et al., 2003). This is also the reason why Kleijn et al. (2019) have found positive effects especially for difficult texts.

STUDENT CHARACTERISTICS THAT AFFECT SOLVING REALITY-BASED MATHEMATICAL TASKS

While experienced readers can resolve less explicit coherence structures, connectives might facilitate the linking of information for less experienced readers. According to some studies (cf. Becker & Musan, 2014; Johnston & Pearson, 2014), secondary students and language-proficient fourth graders benefit in particular from the explication of coherence relations. Based on previous studies (Kamalski et al., 2008; Moritz, 2011; O'reilly & Mcnamara, 2007) it seems that particularly among younger students, competent readers can benefit from more coherent texts, while among adults, conversely, readers with lower reading proficiency tend to benefit from a higher degree of text coherence. With regard to reality-based tasks, however, it has not yet been investigated whether readers with higher or lower language skills are more likely to benefit from an improved coherence structure.

Another factor that can support the formation of an adequate situation model is prior knowledge, as it can help 'relate distant components in texts and integrate what has been read into existing knowledge structures' (Schmitz, 2016, p. 93). However, improved text coherence may compensate for this advantage. Another characteristic closely related to prior knowledge is the reader's interest in the topic, which can have a major impact on the reader's motivation. Dealing with a topic from one's own field of interest is associated with positive feelings (cf. Schiefele, 1999) and can therefore be an intrinsic motivation when it comes to understanding a text (Alhamdu, 2016; Renninger & Hidi, 2022).

Based on the above, the following central research questions emerge:

1. Do connectives influence the understanding of coherence relations in mathematical reality-based tasks and thus also the formation of a suitable situation model?
2. Does the use of connectives affect the solution rate for the mathematical task?

The assumption made here is that using connectives generally has a beneficial effect. It may also influence the time taken by students to complete the tasks, potentially leading to faster processing of what is read. However, it is also possible that only some of the students benefit from the explication of the meaning context. Therefore, two subordinate questions arise:

3. Do students with high and low linguistic proficiency show similar changes in solution rates when coherence relations are explained using connectives?
4. Does prior knowledge and interest in the topic affect whether students show changes in solution rate depending on the use of connectives?

It can be assumed that students with lower linguistic proficiency and students with little interest and prior knowledge may especially benefit from the use of connectives.

MATERIALS AND METHODS

In order to test whether the use of connectives can increase students' understanding of reality-based tasks and thereby help to create a suitable situation model, mathematical reality-based tasks were modified to create two variants with identical content that differed only minimally in terms of their syntactic complexity. All tasks started with an item stimulus consisting of a relatively long text (mean [M] = 219 words) describing the problem situation (**Figure 3**).

Varroa Mites

Most bee colonies suffer from a type of mite known as Varroa, which is a parasite. It multiplies extremely fast in a hive and damages the larvae of the bees. Even if there are on average only 50 female mites in the hive at the beginning of spring, by late summer there are already more than 2,500 mites. The mites have a special reproduction cycle that lasts only 12 days. At the beginning of spring, the first cycle of reproduction begins when the 50 female mites attach themselves to nurse bees. These are special bees that are responsible for feeding the bee larvae in their cells. As soon as a nurse bee feeds a larva in a cell, the mite secretly goes with it into the bee larva's cell. The mite remains there even when the bee with a wax cap closes the cell. The female mite now begins to lay eggs in the cell, from which initially only male mites hatch after about 70 hours. More eggs hatch 30 hours later, all of which are female. Next, 150 hours after hatching, these female mites are sexually mature, whereupon the male mites mate with them in the cell. When the nurse bees open the cell lids two days later, the cleaning bees remove all the male and most female mites. However, a total of 3 mated female mites survive per infested cell, completing the first reproductive cycle. Now, these 3 female mites can be transported by nurse bees to the next cells, where the reproduction cycle starts all over again.

Figure 3. Example item stimulus Varroa mites (Adapted from Leiss et al., 2024)

All item stimuli were first designed in collaboration between educational mathematicians and linguists. Afterwards, the two linguistic versions were elaborated. The only difference between the versions, apart from a few unavoidable deviations in word order, was that relational coherence was expressed more implicitly in one case and more explicitly in the other by using connectives. Other coherence markers – such as pro-forms, text deixis, or recurrence–could occur in both variants, which means that both variants are coherent texts that allow the reader to form a suitable situation model. Previous studies (cf. Kamalski, 2007) often varied several coherence markers at the same time, which either led to significantly different sentence lengths between the two variations or added new components of content; both is avoided in this study.

Two approaches were chosen to examine which of the two variants was more effective in enabling students from grades 7 to 10 to create a suitable situation model. Firstly, the students were asked questions concerning their understanding of the information and relations given in the text. The relations in question had to be essential for solving the mathematical tasks that were posed afterwards. At the same time, they aimed at those relations that were expressed implicitly in one variant and explicitly by means of connectives in the other. Nine reading comprehension questions were developed for each item (**Figure 4**).

Using only the information in the text, evaluate whether the statement is true or false or whether it is impossible to judge with only the information given.	Right	Wrong	Statement not assessable with the info given from the text
With each reproductive cycle, exactly 50 mites are added.	☐	☐	☐
One fertilized mite results in three fertilized mited per cycle.	☐	☐	☐
In spring, about 2500 mites live in the hive	☐	☐	☐
The number of mites triples with each reproductive cycle	☐	☐	☐
A fertilized mite dies after 3 reproductive cycles.	☐	☐	☐
…			

Figure 4. Comprehension items of the modelling task Varroa mites (Adapted from Leiss et al., 2024)

Secondly, the students were instructed to solve tasks from the field of mathematical functions related to the item stimulus (**Figure 5**).

Which one of the following formulas gives the number of female mites after exactly 5 cycles of reproduction in the hive?

☐ 50 * 5
☐ 50 * 3 * 5
☐ 50 * 3 * 3 * 3
☐ 50 * 5 * 5 * 5
☐ 50 * 3 * 3 * 3 * 3

Figure 5. Mathematical task Varroa mites (Source: Authors' own elaboration)

In total, 12 item stimuli, six mathematics tasks, and 54 comprehension questions were developed (**Figure 6**).

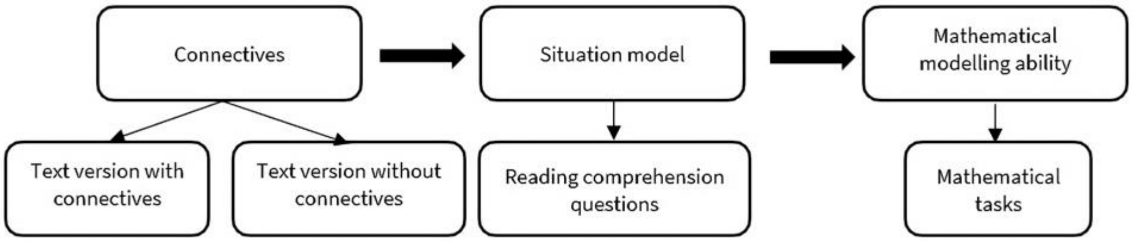

Figure 6. Schematic representation of task structure (Source: Authors' own elaboration)

On average, each student read four items in one of the two linguistic variants. The SoSci Survey web application (Leiner, 2019) was chosen to conduct the study because it allowed for the implementation of a rotational design with random assignments of tasks. SoSci also automatically measures the time students need for each task. In order to investigate the impact of the different contexts of the six tasks, the students self-reported their contextual prior knowledge and interest in the respective topic for each context after each item. All six contexts were rated by at least 145 students (M = 158, standard deviation [SD] = 8, min = 145, max = 169) in terms of the interestingness of the context on a 4-point Likert scale (1 = not interesting, 2 = somewhat interesting, 3 = rather interesting, 4 = very interesting) (M = 2.4, SD = 0.92). In addition, the students also self-reported their prior knowledge on the topic of the tasks for all texts on a similar 4-point Likert scale. The ratings resulted in an average value of 2.3 (SD = 1) regarding the students' prior knowledge of the contexts. The results were then used to form two groups: students with high and low prior knowledge and students with high and low interest in the topic.

The students' language proficiency was measured using a shortened variant of a C-test (5 minutes) as a reliable and valid measure of their general language competence (Grotjahn, 2014). It measures the students' receptive and productive language skills in the domains of lexis, grammar, and orthography. Given that the 20-25 gaps per text can be scaled as largely independent test items (Harsch & Hartig, 2016), only one text with a total of 25 gaps was used for reasons of test economy. A standardized scoring method was used in which each gap was coded as an individual item. The test's internal consistency was measured with a Cronbach's alpha of 0.87, indicating its high reliability. The results of the test were then used to generate quartiles, which categorize the students into four performance groups in order to identify outliers and allow for group comparisons. In addition, a questionnaire was used in which background variables such as mathematics and German grades, migration background and the number of books at home as a variable for socio-economic background were surveyed.

Student Characteristics

The data were collected at a comprehensive school in Northern Germany (7^{th} to tenth grade; n = 390). Of the participants, 42% were female, 51% were male, and 7% self-identified as non-binary. The average age was 14.36 years (SD = 1.47 years), and 33% of the participants had a migration background, meaning that one of the parents or the student was born in a country other than Germany. The number of students with a migration background is slightly above the German average in the sample. The average maximum parental education level was 12.3 years (SD = 1.72), which is slightly below the German average. In terms of the number of books at home, the mean of the five categories: 1 (0-10 books), 2 (11-25), 3 (26-100), 4 (101-200), 5 (more than 200 books) was 3, which is also slightly below the German average of 3.5 as reported in the TIMSS study by Schütz and Wößmann (2005). Most students (28.8%) stated that they had 26-100 books at home.

Analysis

For research question 1 and research question 2, descriptive statistics were calculated. Then, significant group differences between students who solved the task with and without connectives were assessed using ANOVA statistics. For all analyses, a significance level of 0.05 was used. Since comprehension questions and mathematical tasks were presented on a single page, only the cumulative time was available for further calculations. Sato et al. (2010) suggested that applying the item-response-theory models for estimating the students' achievement scores, compared to using the sum scores or the percentage correct, is more suitable to detect the effects of different linguistic versions. Moreover, for analyzing the moderator effects between the personal characteristics (e.g., language proficiency) and the item attributes (the variants with and without connectives), explanatory item response models (EIRMs) are adequate and sensitive (Meulders & Xie, 2004). The EIRM is an approach to cognitive assessment in which explanatory measurements are employed, utilizing item and person covariates to explain what is being measured (De Boeck et al., 2016). Thus, for the third research question, EIRMs provide a framework for modelling the item responses directly as a function of the item or personal predictors, or a combination of both (Wilson, De Boeck, & Carstensen, 2006). This makes them especially suitable for the present analysis, as the item responses are expected to depend on an interaction between the items' linguistic characteristics and the students' general language proficiency. The models were specified as hierarchical generalized linear mixed models (GLMMs), with item responses nested both within students and items (e.g., De Boeck et al., 2011). The item variant and the student characteristics, as well as their interactions, were defined as fixed effects. The models were estimated using the lmer function of the lme4 package in R (Bates et al., 2011).

RESULTS

Research question 1 and research question 2 asked whether the explicit marking of coherence relations by means of connectives influences the formation of a suitable situation model (measured by reading comprehension questions) and on the solving of the mathematical task. On average, the students in the sample correctly solved 23% of the mathematical tasks and 48% of the reading comprehension items.

As **Figure 7** shows, the use of connectives did not affect solution rates for the mathematical tasks. However, it did affect the solution rate of reading comprehension questions. When the students were given the reading comprehension questions after reading the variant with connectives, 49.72% of the questions were answered correctly. For the variant without connectives, only 46.74% were solved correctly. These differences were statistically significant ($F = 7.61$, $p < 0.01$) (**Figure 8**).

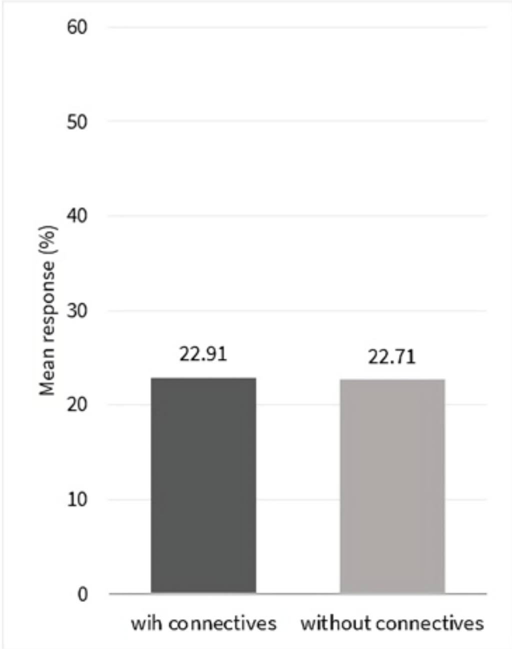

Figure 7. Solution rates for the mathematical tasks (Source: Authors' own elaboration)

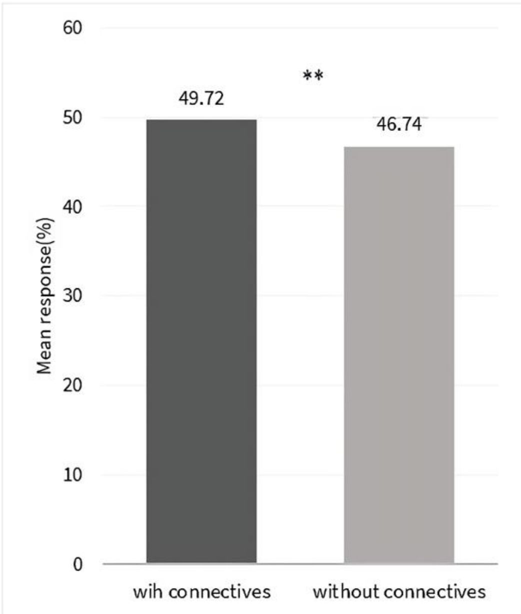

Figure 8. Solution rates for the reading comprehension questions (Source: Authors' own elaboration)

The time difference between the text variants with and without connectives was minimal, with a two-sample t-test showing a non-significant result ($t = 1.183$, $p = 0.2368$). The mean time for processing comprehension questions and mathematical tasks in the version with connectives was 18.39 minutes, and for the version without connectives, it was 18.21 minutes.

Research question 3 and research question 4 asked if student characteristics such as language competence, prior knowledge, or interest in the topic moderate the possible effects of comprehension difficulties. Plausibly, general language proficiency was a strong positive correlate for the ability to solve both the comprehension questions and the mathematical tasks. The quartile with the lowest general language proficiency correctly solved 40% of the comprehension questions and 19% of the mathematical items, while the quartile with the highest general language proficiency was able to solve 56% of the comprehension questions and 28% of the mathematical items (**Figure 9**).

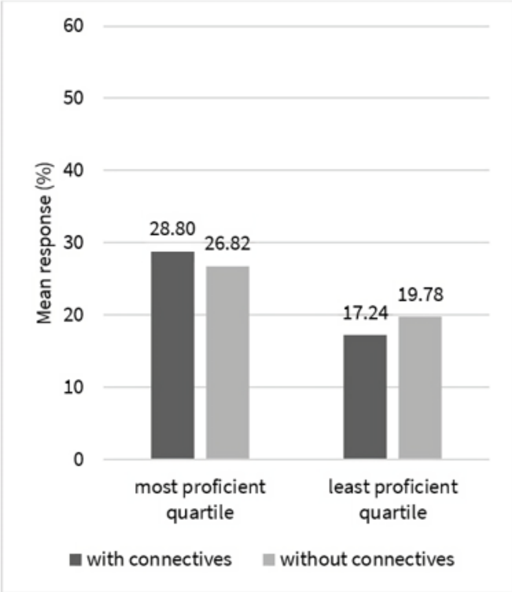

Figure 9. Solution rates for the mathematical tasks (Source: Authors' own elaboration)

As expected, the students in the lowest quartile benefited from the use of the connectives and were able to solve the comprehension questions significantly more often in the variant with the connectives (42.47%) than without (36.61%). However, this result was not found in the quartile with the highest language proficiency: the solution rates for both text variants were comparable (55.41% and 56.95%, respectively). Surprisingly, the mathematical tasks showed the opposite result: the quartile with the best language skills was able to solve the tasks slightly more often when text coherence was supported by connectives, while the quartile with the lowest language skills scored even lower solution rates after reading the text variant with connectives (**Figure 10**).

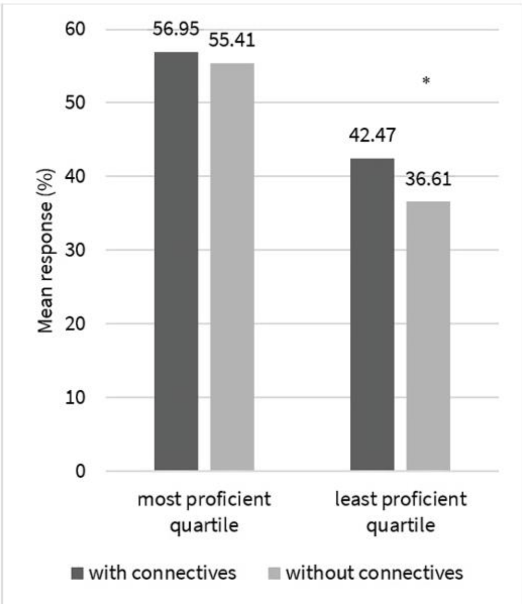

Figure 10. Solution rates for the reading comprehension questions (Source: Authors' own elaboration)

For research question 4, whether prior knowledge and interest in the topic affected if students could benefit from the use of connectives, solution rates were compared separately for the two interest and prior knowledge groups for the two text variants. There were only minor differences between the groups. For the comprehension questions, the solution rates for the variants with and without connectives in the low-interest group were similar (49% and 48%, respectively). In the high-interest group, the solution rate for the variant with connectives was higher than for the variant without them (48% vs. 43%, $p = 0.2012$), but this difference was not statistically significant. Meanwhile, in the low-prior-knowledge group, the solution rate for the variant with connectives was significantly higher than for the variant without them (50% vs. 47%, $p = 0.0183$). However, the high-prior-knowledge group did not show significantly different solution rates between the two text variants (49% and 47%, respectively). Interestingly, the solution rates for the groups with high levels of prior knowledge and interest were lower on average than for the groups with low levels of prior knowledge and interest. The results also indicate that the presence of connectives had a positive effect on solution rates in the low-prior-knowledge group but not in the high-interest group or the high-prior-knowledge group. In terms of the mathematical tasks, the differences between the two interest groups and between the two prior knowledge groups appeared to be quite minimal as well.

The number of books at home played a moderating role in student performance, as revealed by ANOVA analyses. Concerning comprehension questions, a significant correlation was established between the number of books and performance (F [1, 8,006] = 18.39, p < 0.001). Similarly, an analysis conducted for the mathematical tasks indicated a less pronounced impact of the number of books on performance (F [1, 853] = 4.646, p = 0.0314). Regarding the influence of migration background, its effect on mathematical tasks was not found to be significant (F [1, 861] = 2.462, p = 0.117), while it was highly significant for comprehension questions (F [1, 8,006] = 18.39, p < 0.001). Furthermore, when examining the parental education level, significant differences were observed for comprehension questions (F [1, 6,774] = 16.06, p < 0.001), while the impact on mathematical performance was not significant (F [1, 718] = 2.539, p = 0.111) either. While the number of books at home and the parental education level are part of the students' socioeconomic background, the correlation values measured by a correlation matrix suggest that the variables do not measure the same construct. The correlation values between the variables were close to zero, indicating that there is no linear relationship between them.

Furthermore, the influence of grades in German and mathematics on performance in the comprehension questions was investigated. A significant correlation emerged between German grades and the correct solution of comprehension questions (F [1, 6,991] = 14.18, p < 0.001), indicating that better German grades were correlated with enhanced performance in solving comprehension questions. Likewise, the analysis of mathematics grades revealed a substantial impact on performance (F [1, 7,125] = 45.61, p < 0.001), suggesting that better mathematics grades were also linked to better performance in solving comprehension questions. Moreover, the impact of mathematics grades on solving mathematical problems was examined. The analysis indicated a significant effect of mathematics grades on performance in the mathematical tasks (F [1, 752] = 8.028, p = 0.00473), whereas German grades did not influence this aspect (F [1, 740] = 0.007, p = 0.934). In addition, student variables originally elicited for sample characterization such as gender or age were also analysed. There were neither statistically significant differences in reading comprehension task performance nor in the solving of mathematical tasks between males and females or between different age groups in the sample.

To estimate the fixed and random effects of the individual variables, four models were evaluated using a GLMM for the mathematical tasks and for the comprehension questions. Model M1 and model R1 analyze the prediction of solving the mathematical tasks and the reading comprehension questions based on the students' characteristics only. Model M2 and model R2 include the effect of the use of connectives on both aspects. Model M3 and model R3 also integrate interest in and prior knowledge on the topic of the item. Model M4 and model R4 then test for possible moderation effects by including interaction terms between student characteristics and the text variant with connectives (**Table 1**).

Table 1. Prediction of students' mathematical results by student characteristics and two variants of the item, including interaction effects

	Model M1		**Model M2**		**Model M3**		**Model M4**	
	Odds ratios	**p**	**Odds ratios**	**p**	**Odds ratios**	**p**	**Odds ratios**	**p**
(Intercept)	0.04	**0.001****	0.03	**0.001****	0.04	**0.001****	0.02	**0.006****
Student characteristics								
Gender	1.04	0.846	1.04	0.834	1.03	0.871	0.87	0.646
Language proficiency	1.36	**0.005****	1.36	**0.005****	1.37	**0.004****	1.46	**0.016****
Grade mathematics	0.72	**0.013***	0.72	**0.013***	0.72	**0.010***	0.56	**0.003****
Grade German	1.12	0.406	1.13	0.383	1.15	0.296	1.12	0.553
Migration background	1.10	0.736	1.10	0.737	1.06	0.840	1.28	0.551
Books at home	0.96	0.732	0.96	0.753	0.95	0.643	0.84	0.334
Parents' highest educational qualification	1.08	0.244	1.08	0.229	1.08	0.247	1.12	0.226
Connectives			1.19	0.381	1.17	0.427	1.12	0.460
Interest					1.19	0.163		
Prior knowledge					0.93	0.539		
Moderator effects								
Gender × connectives							1.43	0.350
Language proficiency × connectives							0.87	0.521
Grade mathematics × connectives							1.65	0.061
Grade German × connectives							0.95	0.844
Migration background × connectives							0.75	0.606
Books at home × connectives							1.31	0.245
Parents' highest educational qualification × connectives							0.92	0.531
σ^2	3.29							
τ_{00}	0.23_{id}							
ICC	0.07							
N	163_{id}							
Observations	597							

For the mathematical tasks, the GLMM analysis revealed that language proficiency and grades in mathematics remain statistically significant predictors in all four models. As language proficiency and mathematics grades increase (in the German grading system, 1 is the best grade and 6 is the worst grade, which explains the odds ratios below 1), the probability for students to correctly solve the mathematical tasks increases as well. All other student characteristics, such as gender or socioeconomic background, show no significant effects on the ability to solve the mathematics tasks. In model M2, the integration of connectives also does not show significant effects on the ability to solve the tasks when controlling for student characteristics. Model M3 confirms that interest and prior knowledge do not have a significant effect on the solution of the mathematics tasks either. The interaction analysis in model M4 revealed that none of the student characteristics in question had a moderating effect on the relevance of the connectives in the item stimulus (**Table 2**).

Table 2. Prediction of students' reading comprehension by student characteristics and two variants of the item, including interaction effects

	Model R1		**Model R2**		**Model R3**		**Model R4**	
	Odds ratios	**p**	**Odds ratios**	**p**	**Odds ratios**	**p**	**Odds ratios**	**p**
(Intercept)	1.00	0.991	0.96	0.902	0.78	0.674	0.97	0.950
Student characteristics								
Gender	0.88	0.054	0.88	**0.048***	0.83	0.141	0.96	0.609
Language proficiency	1.15	**< 0.001*****	1.15	**< 0.001*****	1.14	0.061	1.24	**< 0.001*****
Grade mathematics	0.90	**0.021***	0.91	**0.021***	0.84	0.073	0.95	0.323
Grade German	0.98	0.624	0.98	0.653	0.94	0.465	0.96	0.514
Migration background	0.67	**< 0.001*****	0.66	**< 0.001*****	0.63	**0.009****	0.70	**0.002****
Books at home	0.98	0.592	0.98	0.579	0.91	0.212	1.00	0.999
Parents' highest educational qualification	1.03	0.266	1.03	0.252	1.06	0.187	0.99	0.821
Connectives			1.09	0.158	1.02	0.907	0.97	0.956
Interest					1.01	0.850		
Prior knowledge					1.00	0.971		
Moderator effects								
Gender × connectives							0.84	0.105
Language proficiency × connectives							0.88	**0.026***
Grade mathematics × connectives							0.92	0.218
Grade German × connectives							1.05	0.535
Migration background × connectives							0.92	0.586
Books at home × connectives							0.96	0.581
Parents' highest educational qualification × connectives							1.07	0.062
σ^2	3.29							
τ_{00}	0.07_{id}							
ICC	0.02							
N	163_{id}							
Observations	5,655							

Note. For the analyses, all metric variables were z-standardized; *p < 0.05; **p < 0.01; ***p < 0.001; & Marginal R^2/conditional R^2 = 0.028/0.050

With regard to the reading comprehension tasks, the GLMM analysis found significant effects of language competence and migration background, which remain stable across all models. While language competence has a clearly positive effect on the solution of the comprehension questions, students with a migration background show lower performance rates. However, this effect becomes weaker as more variables are included in the analysis to provide clarification. Male students also show slightly weaker performance overall in solving the comprehension questions, although this effect only becomes significant in model R2. Surprisingly, mathematics grades, but not German grades, show a positive effect on the solution of the reading questions, which becomes significant in model R1 and model R2. In the GLMM analysis, neither connectives nor interest or prior knowledge shows significant effects on the solution of the comprehension questions when controlling for student characteristics. In contrast, the interaction analysis in model M4 confirms that students with high language proficiency even show slightly weaker results in answering the reading questions when they were given the text stimulus including connectives.

DISCUSSION AND CONCLUSION

The study's findings shed light on the complex relations between text coherence, student characteristics, and performance in mathematical reality-based tasks. This is linked to the question of whether the linguistic design of reality-based tasks creates difficulties that favor or disadvantage certain groups of students in performance situations. The study's experimental design allows theoretical assumptions about the influence of connectives on text comprehension to be examined individually and in interaction with student characteristics with regard to their effect on task difficulty.

This study stands out from previous research in three keyways. First, it explores the relationship between text comprehension and mathematical modeling skills. Although such a connection is assumed, it has not yet been clearly demonstrated. Second, it focuses on students in grades 7 through 10, a demographic that has been underexplored in this context, thereby offering deeper insights into developmental processes during this critical educational phase. Third, the study manipulates text coherence solely through the presence or absence of connectives, unlike other studies that may increase coherence through additional background information. This approach enables a more precise analysis of the effects of connectives while controlling for linguistic variables such as sentence length and informational content.

The results consistently indicate that language proficiency is indeed a significant predictor of performance. As students' language proficiency increases, students are more likely to solve both the reading comprehension questions and the mathematical tasks correctly. However, the main hypothesis – that students generally benefit from the explication of coherence relations by means of connectives – could not be fully confirmed.

Descriptive statistics did show a significant effect of the use of connectives on answering the reading comprehension questions, while the use of connectives did not have a significant effect on mathematical task performance or on the time the students needed to complete the tasks. Descriptive and interaction analysis also confirmed that students with lower levels of linguistic proficiency showed better results in the reading comprehension tasks when coherence is improved by connectives. Surprisingly, this did not result in better performance in the mathematical tasks. It can therefore be assumed that students with lower language proficiency benefit from the use of the connectives to create the situation model, but they are not able to use this advantage to solve the mathematical tasks. This implies that while connectives do affect the initial stages of the modelling cycle (understanding and structuring, as shown in **Figure 1**), their influence on the subsequent phases seems to be less pronounced than initially believed. It can be assumed that a distinct skill set is crucial for the translation of real-world information into mathematical concepts, and these competencies are not adequately supported by the use of connectives.

Another rather surprising result was that students with high language proficiency showed slightly weaker performance in answering the reading comprehension questions when given the text stimulus with connectives. One possible reason could be that in this study, for the more explicit variation, every single coherence relation was also explicated by a connective, potentially making the content self-evident to experienced readers. Thus, the use of a connective may even be perceived as irritating, since readers may seek reasons for the explicit form. This methodological choice was done on the one hand to create the maximum possible contrast and on the other hand because so far, there have been no conclusive findings as to which groups of connectives help to understand reality-based tasks and which do not.

This raises the question as to when connectives are beneficial and when they can even hinder comprehension. The answer would demand a comprehensive exploration of reader and text characteristics. The effectiveness of connectives may depend on several factors, besides the reader's linguistic proficiency and interest in and prior knowledge on the topic, also on the semantics of the connectives, the (syntactic) context in which they are used in the text and the reader's expectations. These factors collectively contribute to whether connectives are perceived as beneficial or detrimental to comprehension. Further research taking these variables into account is essential to provide valuable insights and to create a more informed basis for the strategic use of connectives that promotes equal learning opportunities for all students.

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Ethical statement: The authors stated that all relevant ethical guidelines and principles were carefully considered in the preparation of this scientific article. The conduct of the research, as well as data collection, analysis, and interpretation, was performed in strict adherence to ethical standards to ensure that potential impacts on humans and the environment were minimized. Owing to the fact that in Germany no formal approval by an ethics committee is required prior to conducting a scientific study, no such statement exists. However, prior to data collection, an audit is conducted by the state education authority of Lower Saxony, which reviews the study design, instruments, and process in advance. The authors further stated that this review includes compliance with ethical standards in the research process (including anonymity of subjects, voluntariness of participation, and confidentiality in data management) and only after successful assessment can the study be implemented. A comprehensive ethical evaluation was conducted prior to the study; this weighed all potential risks and benefits of the research. Any interaction with human participants was voluntary and informed consent was obtained. Participant privacy and confidentiality were always respected, and appropriate measures were taken to maintain anonymity. All study participants provided informed consent.

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