

Understanding mathematical word problem-solving skills among elementary schoolers through meta-analyses

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Honored Custos, honored Opponent, dear members of the audience

We've all seen word problems like: "Jane has two red apples and seven green apples. How many apples does Jane have altogether?" But have you ever thought explicitly why such tasks are introduced in mathematics classes? Maybe this example sheds more light: "Suppose you want to play tennis with friends at six. After work, you drive home, take a 30-minute walk with your dog, have a snack, and then drive 10 minutes to the hall. What time do you need to leave work to get there five minutes early?"

Mathematical word problem-solving skills help students practice using mathematics in everyday situations—whether counting the amount of fruit or planning a trip to the tennis hall (Gravemeijer et al., 2017; Strohmaier et al., 2021; Verschaffel et al., 2020). In our modern world, especially through technological innovations, the role of mathematics is growing. At the same time, machines do much of the mathematics for us (Gravemeijer et al., 2017). Students need to be able to analyze and orchestrate information, adapt to different situations, and ultimately, solve problems (Geisinger, 2016). It follows that being proficient in solving mathematical word problems can be seen as one of the most important aspects of mathematics education in modern society.

The importance of being proficient in mathematical problem-solving is also recognized in various global initiatives and policies. For instance, the United Nations Sustainable Development Goals (n.d.) emphasize that math skills are crucial for people to succeed in work. Similarly, the European Commission (2025) recognizes mathematics as one of the focus areas in education due to the transversal skills of problem-solving and critical thinking that learning mathematics may foster. Finally, the World Economic Forum Future Jobs Report (2025) emphasizes problem-solving



abilities as one of the core skills for success in work life.

Despite this recognition, we see worrying global trends in students' learning of mathematics and, especially in mathematical word problem-solving (European Commission, 2025). For example, the PISA 2022 mathematics assessment across OECD countries showed that one in three 15-year-olds struggles even with simple real-life math tasks (Organisation for Economic Co-operation and Development, 2023). Similarly, teachers report that word problems are often the weakest area when students start middle school (Elliott, 2023). Indeed, it appears that actions need to be taken to ensure that students before adolescence and adulthood are better prepared to apply mathematics in various situations.

Research shows that learning mathematics builds on itself and contributes to later financial and well-being outcomes (Davis-Kean et al., 2022; Ritchie & Bates, 2013; Watts et al., 2018). Children who do well early in mathematics often keep doing well, while those who struggle usually keep struggling unless they receive adequate educational support. This highlights that support in mathematical word problem-solving needs to be provided already at the beginning of students' educational paths. But how do we develop mathematics education that ensures students develop these critical skills? One approach is to understand the comprehensive and complex set of factors that shape the learning of mathematical word problem-solving skills (Alcock et al., 2016; De Smedt, 2022; Gilmore, 2023).

Mathematical skills do not develop in a vacuum (Alcock et al., 2016; Gilmore, 2023). Instead, they are shaped by many factors, both inside the student and in their environment (Alcock et al., 2016; Darling-Hammond et al., 2020; De Smedt, 2022). These factors may be divided into individual characteristics and learning experiences. In terms of individual characteristics, we can think of the process of a student solving a word problem. Students need to read the problem, do the calculations, and have the motivation to try to solve the task (Kintsch & Greeno, 1985; Lin, 2021). Therefore, language skills, calculation skills, and students' affective characteristics are likely related to their performance. At the same time, students' learning experiences, the way students are taught at school or supported at home, also shape how they learn mathematics (De Smedt, 2022; Gilmore, 2023).

Within learning experiences, aspects of a formal learning environment include, for instance, task characteristics and educational interventions. If a task includes extra unnecessary information or asks students to think about a real-world situation, solving the task can become much harder. This matters for how teachers

introduce such tasks in classrooms (Daroczy et al., 2015; Jaffe & Bolger, 2023). Similarly, the way teaching is done—how much, by whom, and for which students—also affects the learning of word problems (Alcock et al., 2016; Myers et al., 2022). Studying educational interventions such as mathematical word problem-solving interventions is one way to try to find out how these aspects influence students' learning.

Though research in the learning of mathematics is growing, many studies still look at just one factor that potentially influences the learning of mathematics at a time (see Amland et al., 2024; Breit et al., 2025; De Smedt, 2022; Gilmore, 2023). This approach often falls short in describing the comprehensiveness of factors that need to be taken into account when we study the learning of mathematics (Alcock et al., 2016). On top of that, we often talk about mathematics as a whole, instead of looking at specific skills (Amland et al., 2024; De Smedt, 2022; Gilmore, 2023). This is problematic since mathematics is not a unitary construct (Dowker, 2014; Fuchs et al., 2008). A child who can calculate well may still struggle with word problems that use the same calculations (Dowker, 2014). Therefore, the question arises: which characteristics potentially influence students' learning of mathematical word problem-solving skills at the beginning of formal education?

The overall aim of this thesis was to investigate individual, task, and educational interventions' characteristics associated with elementary schoolers' mathematical word problem-solving skills. The aim was addressed with three research questions, to which each was answered with a systematic review and meta-analysis. The first and second research questions investigated the set of individual and task characteristics related to elementary schoolers' mathematical word problem-solving, whereas the third looked at the impact of educational interventions on these skills.

A systematic review is a research method where we gather published studies on a given topic (Page et al., 2021; Siddaway et al., 2019). For the systematic review, five electronic databases were searched, and a citation search was conducted. Out of around 6,000 abstracts to 1,300 full-text articles, 323 research reports met the criteria and were included across the three sub-studies. These data were used to perform statistical analyses beyond the ones that were reported in the original studies, called meta-analyses (Borenstein et al., 2009).

The first research question, and therefore sub-study I (Vessonen et al., 2025a), addressed the extent to which individual characteristics – like reading skills, memory, mathematical skills, and motivation - relate to elementary schoolers' ability to solve mathematical word problems. The results showed that all investigated

individual characteristics were connected to how well children solved word problems. For instance, the findings showed that students with better overall language and reading skills and calculation abilities were also likely to be more successful word problem-solvers. But also, less obvious and less investigated skills—like naming numbers, comparing magnitudes, and trusting your own ability to solve word problems—turned out to matter too. These findings reinforce the idea that word problem-solving skills require the interplay between multiple cognitive and affective processes.

The second study (Vessonen et al., 2024) focused on the word problems themselves. It addressed the extent to which characteristics of the mathematical word problems, task characteristics, are associated with students' word problem-solving performance. These task characteristics included dimensions such as the number of mathematical operations required in the task, whether irrelevant information was present, or how familiar the student was with the mathematical word problem situation. The findings demonstrated that indeed, a range of task characteristics does affect students' success in mathematical word problems. The findings especially highlight that elementary schoolers often struggle with multi-step problems or when the wording doesn't clearly match the math operation. One explanation for these tasks being more demanding is that they likely put more strain on the processing of such tasks, or that students use unhelpful strategies to solve these tasks. These results demonstrate that word problem-solving skills are indeed skills, in the plural sense.

Finally, the third research question and sub-study III (Vessonen et al., 2025b) aimed to determine the type of mathematical word problem-solving interventions – programs for teaching word problems- that are the most effective in supporting elementary schoolers' mathematical word problem-solving skills. To find this out, a range of student, intervention, and design methodology aspects of mathematical word problem-solving interventions were investigated. The findings showcased that mathematical word problem-solving interventions are generally highly effective in helping students learn mathematical word problems. This indicates that in many areas of the world, we have effective ways to teach word problem-solving. However, some characteristics of the intervention and methodology modified this intervention's effectiveness. Indeed, interventions worked best when researchers ensured that teachers could apply the interventions consistently, following a plan. For instance, in these cases, teachers had scripts or training for implementing the

lessons. This implies that structured and concise teaching of word problems would be a key to better student outcomes. Interestingly, studies with standardized rather than researcher-generated measures and weaker research methods showed larger student learning of the intervention. This reminds us to look carefully at how studies are done, not just at the results.

What does the scientific and practical community gain from these findings? The findings underscore the complex nature of learning mathematical word problems in elementary school. These skills likely depend on students' cognitive and affective processes, features of the problem itself, and the quality of instruction. Especially, children with weaker language-related skills and basic mathematical skills may often struggle with word problems. Therefore, students who are likely to struggle with word problems could be recognized preventatively based on their language, calculation, and number naming abilities. Also, explicitly teaching how to solve word problems that have different, more demanding task characteristics is needed.

From a theoretical perspective, the findings highlight that future research efforts should further incorporate the more overlooked characteristics, such as affective characteristics and basic mathematical skills, and adopt a multidimensional view of mathematical word problem-solving. This is important considering the demanding nature and extra effort that solving word problems may require. To move forward with our theoretical and practical understanding of word problem-solving skills, we need to think about the child, the task, and the teaching together.

From counting the number of fruits to planning a trip to the tennis hall, mathematical word problems help students to apply mathematics in a variety of situations, underlining their importance in modern society (Gravemeijer et al., 2017; Strohmaier et al., 2021; Verschaffel et al., 2020). In light of the findings presented, we need to ensure that elementary schoolers receive high-quality instruction and practice in different types of word problems while considering their individual support needs.

Honored Professor Lieven Verschaffel, I now call upon you to present your critical comments on my dissertation.

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