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Teaching Mathematics and Computer Science

Word problems in different textbooks at the early stage of teaching mathematics- comparative analysis

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Abstract. In a previous research, Csíkos and Szitányi (2019) studied teachers' views and pedagogical content knowledge on the teaching of mathematical word problems. While doing so, they reviewed and compared Eastern European textbooks of Romania, Russia, Slovakia, Croatia, and Hungary to see how world problem-solving strategies are presented in commonly used textbooks. Their results suggested that teachers, in general, agreed with the approach of the textbooks regarding the explicit solution strategies and the types of word problems used for teaching problem-solving. They also revealed that the majority of the participants agreed that a word problem-solving algorithm should be introduced to the students as early as in the first school year. These results have been presented at the Varga 100 Conference in November 2019. As the findings suggested a remarkable similarity between the Eastern European textbook approaches, in the current study we decided to conduct further research involving more textbooks from China, Finland, and the United States.

Key words and phrases: word problem, textbooks.

MSC Subject Classification: 97U20, 08A50.

Introduction

Teaching word problem solving has been an important part of primary school mathematics in many parts of the world for a long time. According to Pollak (1969) solving 'word' problems is the primary way for students to get involved in the application of mathematics. Therefore, the way in which word problem-solving strategies are taught and how word problems are defined in general in different countries are of high importance.

"Word problems can be defined as verbal descriptions of problem situations wherein one or more questions are raised the answer to which can be obtained by the application of mathematical operations to numeral data available in the problem statement" (Verschaffel et al. 2010, p. ix.) Based on this definition, different types of word problems can be distinguished from simple routine tasks to more complicated, realistic ones.

The question is what the purpose of using word problems in primary school textbooks is and what type of word problems are used to achieve the desired goals. According to Palm (2006), one level and function of using word problems can be described as "merely ordinary school mathematics tasks 'dressed up' with an out-of-school figurative context" (p. 42). Another common purpose of using word problems in the classroom is to teach an algorithm that is to be followed step by step and also to teach algorithmic thinking.

According to Csíkos and Szitányi (2019), Hungarian elementary teachers do not find it problematic to introduce a linear, step-by-step solution strategy as early as in grade 1, but they also find it natural to introduce those steps by means of applying them on relatively simple, straightforward, routine word problems. However, while applying a linear, step-by-step solution strategy on a simple arithmetic word problem, there is a chance that many children will find the explicit and consciously followed steps unnecessarily since they immediately and easily would solve the task by mental calculations. There is a danger that the otherwise useful and justified solution steps that may really be valuable when solving more difficult tasks will be considered as part of the hidden curriculum or "didactic contract" (see Verschaffel, Greer, & De Corte, 2000). According to our results (Csíkos and Szitányi, 2019), Hungarian teachers would use a scoring system when assessing students' solutions according to the step-by-step solution strategy, and the lack of any explicit solution step may result in unfavorable test results even though the students have excellent arithmetic skills and a high level of sense-making.

It is obvious that even in one country, different textbooks present different approaches and visuals regarding the teaching of the strategies of word problem solving. According to available results (TIMSS 2011 survey, Balázsi et al. 2012, van Zanten & van den Heuvel-Panhuizen 2018), the majority of elementary teachers use textbooks as the base of teaching mathematics, so there is a great emphasis on how word problems and word problem solving strategies are presented. Our research questions are focusing on the differences and similarities between different textbooks concerning the teaching of word problem solving strategies. When teaching the solving of word problems, is there any explicit demonstration of an algorithm that the students are required to follow? Are there any differences regarding the teaching of word problem solving strategies between Eastern European countries and China or the United States? Is explicit verification a part of the problem solving algorithm presented by the different textbooks?

As a framework for textbook comparison, we used Polya's (1945) heuristics: Understand the problem; Devise a plan; Carry out the plan; Look back. This general four-step model of problem-solving strategy phases has become a dominant part of mathematics education in Easter European countries, but also made a huge impact on the teaching of mathematics in the United States. In Hungary, based on Pólya's work, C. Neményi and Szendrei (1997) presented a scientifically based description of four steps of problem-solving in their textbook for pre-service primary teachers. These steps were the following: understanding the problem, seeking a mathematical model and turning the original problem into a mathematical problem, solving the mathematical problem, and interpretation of the mathematical solution.

Methods

Our research belongs to the type of investigations called textbook analysis and comparison (Fan, Zhu, & Miao, 2013). According to the framework Fan et al. (2013, p. 635.) established for their study, "studies focusing on analyzing the concerned features of mathematics textbooks under study and, in the case of textbook comparison, comparing the similarities and differences of two or more series of mathematics textbooks" can be classified into this category, as well as most of the textbook research published in international research fora.

In our current textbook comparison project, we chose textbooks from Hungary, Russia, Slovakia, Finland, China and the USA. Why the USA-China comparative studies became popular and widespread in the last three decades can be attributed to the growing interest in the success East-Asian countries have in international educational surveys. The other countries involved in this comparative study represent the Eastern-European tradition of mathematics education (for a review on the main characteristics of the Eastern-European tradition see Csíkos, András, Rausch and Shvarts, 2018), except for Finland, which also belongs to the group of top-achieving countries in international mathematics surveys.

In total, the following six mathematics textbooks in the six countries were examined in this study:

Hungary: OFI Mathematics for the 1st grade of elementary school. (Matematika 1. osztályosoknak I. kötet, Oktatáskutató és Fejlesztő Intézet, 2016) This students' textbook corresponds to the official National Core Curriculum, and it is used by the majority of Hungarian schools. The way word problems are introduced and how the solution process is shown, indicate widespread practices teachers are expected to follow.

Russia: Moro, M. I., Volkova, S. I., & Stepanova, S. V. (2011). Mathematics for the 1st grade of elementary school, Part 1. (Математика часть 1.) This mathematics textbook is recommended by the Ministry of Education and Science of the Russian Federation.

Slovakia: Lehotanová, B. (2013). Mathematics for the 1st grade of elementary school, Part 2. (Matematika az alapiskolák 1. osztálya számára 2. rész.) The textbook from Slovakia is a commonly used Slovakian students' book translated into Hungarian, used by students of Hungarian mother tongue living in Slovakia

Finland: Neményi, E., Oravecz, M. & Lampinen, A. (2008). Mathematics for the first grade of elementary school, Part 2. (Matematiikkaa 1b). This Finnish students' textbook is based on the Varga-Neményi method. The Varga-Neményi method has a positive reputation in Finland underlined by experimental results as well (Grevholm, 2009).

United States of America: McGraw-Hill (2011). My Math, Grade 2, Student Edition, Volume 1. McGraw-Hill. My Math is a successful program used in numerous states (e.g., New York) across the United States of America.

China: People's Education Press (2012/2019). Mathematics for the 1st grade of elementary school, Part 1. (数学一年级上册，人民教育出版社，2012/2019) The Chinese students' textbook is one of the most widely used mathematics textbooks for state schools in China. It is published in Beijing and represents the most common practices regarding mathematics education in the People's Republic of China.

In this exploratory study, we selected one textbook from every country, therefore the results cannot necessarily be generalized to other textbooks from the chosen countries. However, since all those textbooks represent long-term cultural and educational practice, the current textbook comparison study may refer to teaching practices across different countries.

Results

Hungary

In Hungarian mathematics teaching and teacher education word problem solving has played a very important role for decades. Word problems are presented in the first grade of schooling with an algorithm to follow that is similar to Pólya's (1945) problem-solving strategy phases. There are mainly two types of word problems introduced in the first years. In the beginning, word problems are rather situations expressed in words with the purpose of representing an arithmetic operation. In Fig. 1 the idea of addition is demonstrated by words and by illustration.

Figure 1. Example of a situation expressed in words with the purpose of representing a simple arithmetic operation (OFI 2016, vol.1, p. 41) The word problem is presented as follows: "The children are picking apples. The boy puts 1 apple in the basket, the girl puts 2. How many apples do they put in the basket altogether? Write it down with an addition.

In the Hungarian textbook, this problem in Figure 1 is not explicitly labeled as a word problem but simply a problem dressed up in words. Since the purpose here is merely to demonstrate a simple arithmetic operation, the word problem solving algorithm is not presented or taught at this point.

The following word problem is the very first task that is explicitly labeled as word problem as manifested in the title of the textbook chapter. As it can be seen in figure 2, the steps students are demanded to learn and apply are presented in parallel with the word problem itself.

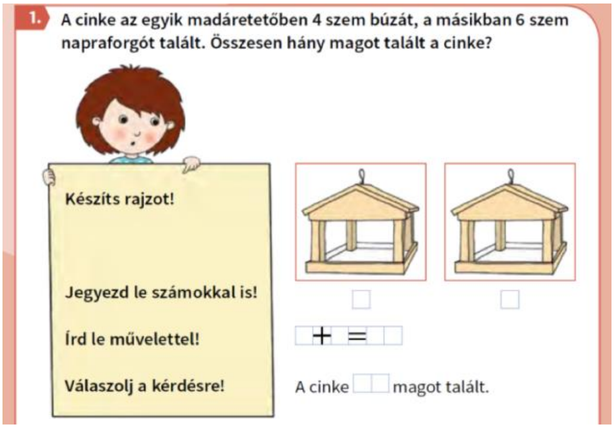

Figure 2. The very first word problem in a Hungarian first-grade students' textbook (OFI 2016, vol. 1, p. 102)

Translation of the word problem text: The titmouse has found 4 wheat grains in one of the bird feeders, and 6 sunflower seeds in the other. How many seeds has the titmouse found altogether?" Translation of the instructions written in bold from top to bottom are as follows: make a drawing, write down with figures, write down with an operation, and answer the question.

The steps of the algorithm presented with the very first word problem in the textbook are not representing all of the steps that students are later expected to utilize, specifically, the step of verification is still missing at this point. The steps cover Pólya's (1945) first step by reading the word problem and by making a drawing and writing down the data with figures, the second step by the interpretation of the problem while making an arithmetic operation, the third step by solving the arithmetic operation, and to a certain degree, the last step of looking back by translating the solution into an answer that corresponds to the original question.

Discussion: We suggest that introducing word problems as a separate chapter in the mathematics textbook indicates the intention to introduce a step-by-step solution strategy that is claimed to be useful for almost all kinds of word problems in the elementary school years and far beyond. Also, the practice of presenting the steps that students are required to apply in parallel with the word problem itself suggests that the teacher is expected to combine the process of understanding and solving the word problem with teaching the step-by-step algorithm and its application. It is questionable whether students are capable of adapting to this kind of parallel thinking and processing of information as early as in their first year of school.

Russia and Slovakia

As Russia and Slovakia represent the Eastern European tradition regarding mathematics education, it was expected that the explicit steps of word problem-solving algorithm based on Pólya's (1945) problem-solving steps are presented in these textbooks, although we did find a difference in the way certain steps of the algorithm were emphasized.

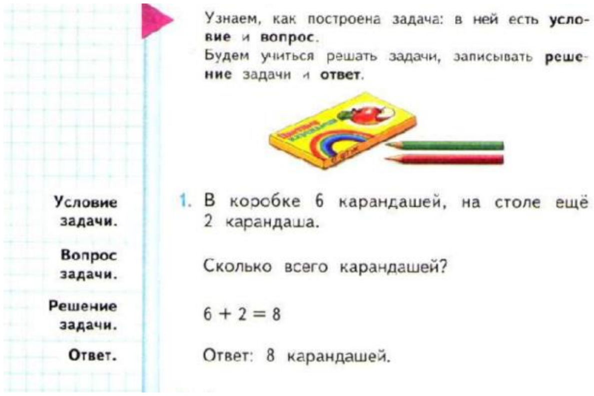

Figure 3. Explicit teaching of the steps of word problem-solving in a Russian textbook (Moro, Volkova and Stepanova, 2011, p. 88) Note: Expressions on the left side of the figure in bold, from the top to the bottom: conditions of the task, question (of the task), problem-solving, and answer.

In the Russian textbook, word problems are introduced with the problem shown in Figure 3 as follows: *"It is known that a task consists of conditions and an answer. We will learn how to solve problems and how to answer them."* This explicit way of presenting the steps of the word problem-solving strategy students are required to follow is similar to the method of the Hungarian textbook.

Comparing the steps of word problem solving in the Russian textbook to the ones that of Pólya's (1945), we can see that here the emphasis is mainly on the first three steps, while there is no sign of explicit verification. Verification is an essential part of the problem-solving algorithm since it gives an opportunity to check the arithmetic operation setup by executing an inverse one. This can be seen in the task from the Slovakian textbook for grade 1 students in Figure 4, where the step of verification is very explicit.

Figure 4. Explicit verification step in the textbook of Slovakia. (Lehotanová, 2013. P. 37.) Note: The word ELLENŐRZÉS means verification.

Discussion: As previously seen in the Hungarian textbook, we think that listing the steps of the algorithm next to the word problem can be interpreted as a strong message for both students and teachers. Such a presentation of the very first word problem in first grade suggests that beyond finding the answer, learning and memorizing the algorithm is also necessary, which raises the issue of inviting learners to solve all arithmetic word problems by following the same steps in this particular order. This idea of teaching an algorithm that is to be followed by all means when solving word problems is problematic when solving word problems that are so simple that students cannot see the purpose of following a problem-solving strategy.

Regarding the presentation of the step of verification in the Slovakian textbook, we find that it can be understood with difficulty, since the drawing of the word problem situation on the left side can already be interpreted both ways, therefore students would not need to apply an inverse arithmetic operation to check the result.

Finland

The Finnish textbook we chose for the analysis is a students' book as an adaptation of the Varga-Neményi method (Tornberg, 2018) Although word problems as a separate chapter only appear around the end of the book 1b, parts of the problem-solving algorithm are presented earlier. In Figure 5, a word problem is presented to demonstrate a simple arithmetic operation. Students are required to make a drawing as part of the solution process. This step corresponds to previous findings of Csíkos and Szitányi (2019, p. 4) where they found that "In most of the textbooks, a component of the solution algorithm of a word problem is the depiction of the text … by making a drawing". Making drawings in order to understand the problem described in words is a step that is required in most of the word problems in the Finnish textbooks. The role of drawings in word problem solution was extensively studied in a design experiment by Csíkos, Szitányi and Kelemen (2012). According to them, several kinds of drawings can be useful, and students' thinking and talking about the different types of drawings and how their drawings may help in word problem solution is an important instructional method.

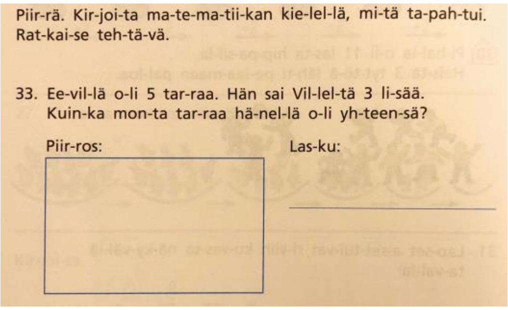

Figure 5. Word problem in the Finnish first grade students' book part 2 (p. 16) The word problem is presented as follows: "Eevillä had five stickers. She got three more from Villeltä. How many stickers did she have in total?" The words under the word problem are the following: Drawing, Calculation. Note: Text on the top of the word problem: Draw. Write down what happened in the language of mathematics. Solve the problem.

In the same textbook, next to the depiction of the problem and writing it down with an operation, another step appears as an important part of the problem-solving algorithm: providing an answer to the question. This is in connection with Pólya's (1945) fourth step of problem solving, "looking back". Near the end of Part 2 in the first grade students' book, there is a whole chapter for teaching word problem solving. The problem-solving strategy consists of the same explicit steps for almost every word problem: drawing, calculation with figures, answer, but there are some interesting exceptions.

Figure 6 presents a unique word problem in this chapter. Here not only the previously mentioned steps are required but also the wording of the question after reading the situation. Formulating a question at the end of a mathematical word problem requires substantial mental efforts from elementary students. According to a textbook comparison study by Cai, Jiang, Hwang, Nie and Hu (2016), the percentage of so-called problem-posing tasks[1] is extremely low in U.S. textbooks as compared to their Chinese counterparts, and - this result of their study is far most relevant to the Finnish case - the percentage of problem-posing tasks is relatively high in the early elementary grades. In

[1] There are several kinds of problem-posing tasks, and it is the fourth type in Cai et al.'s work that is described as *posing questions based on given information*.

general, the importance of using problem-posing tasks is manifested in its presence in the Finnish textbook.

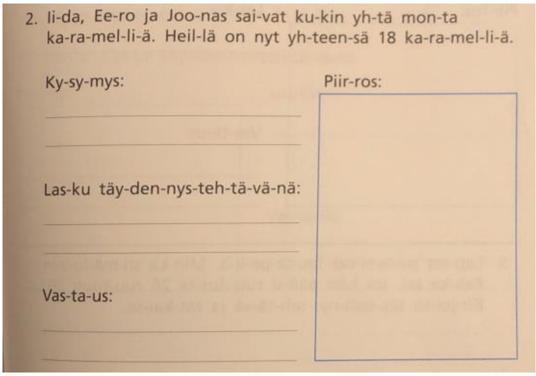

Figure 6. Word problem in the Finnish first grade students' book part 2 (p. 119) The word problem is presented as follows: "Iida, Eero and Joonas each got the same amount of candies. They now have a total of 18 candies." The expressions in the word problem are the following: Question, Drawing, Supplemental calculations, Answer.

Discussion: Analyzing the explicit steps of the word problem solving strategy presented in the Finnish textbook, we found that out of the four steps defined by Pólya (1945), the students are mainly required to focus on understanding the problem with the help of a drawing, devising a plan by translating the problem to the language of mathematics and carrying out the plan by finishing the calculation. Although there are no explicit instructions for checking the answer, turning the result of the calculation into a sentence by answering the question gives the opportunity to look back and reflect on the meaning of the result in connection with the original problem. It is also found that while the problem-solving steps are consequently presented in the word problems, the required steps may vary according to the problem itself. In comparison with the Hungarian and the Russian textbooks, the steps to-be-followed are not represented separately next to the first word problem.

USA

McGraw-Hill My Math program focuses explicitly on problem-solving strategies throughout the whole textbook. According to its common core, the textbooks introduce a new problem-solving strategy in every chapter both in grade 1 and grade 2. The strategies presented in the first grade are the following: ‘write a number sentence’, ‘draw a diagram’, ‘act it out’, ‘make a table’, ‘guess, check and revise’, ‘use logical reasoning’ and ‘look for a pattern’. In second grade, the same strategies are utilized with different contents according to the curriculum. In figure 7, a homework sheet for practicing writing a number sentence as a problem-solving strategy from a second-grade textbook is shown. It can be seen clearly that word problem solving is introduced under the wide concept of mathematical problem solving, and according to Bishop (1982, p. 120) “much of the work is derived from Polya’s (1945) seminal writing”.

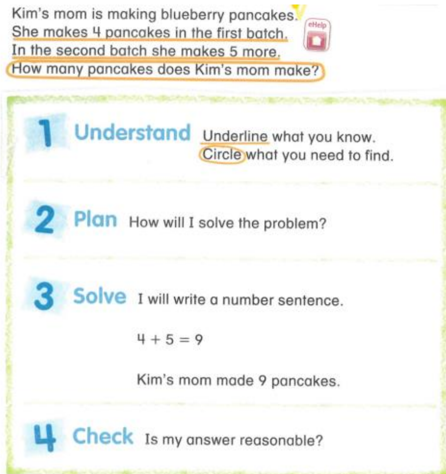

Figure 7. Reviewing the problem-solving strategy of writing a number sentence in the McGraw-Hill My Math Grade 2 (p. 45)

The steps suggested to follow are in a strong connection with the problem-solving steps of Polya (1945). The first step is “understand”. Here students are taught to underline the facts given in the text and circle the question. This step corresponds to Polya’s (1945) first step: understanding the problem. The learners are invited to look for the data and the unknown while learning a way of indicating the necessary information in the text. The second step in the textbook is planning. Here learners are required to find the connection between the data and the unknown. Following the planning comes the main part of the problem-solving strategy, writing a number sentence. Here, we can talk about the third step of Pólya’s (1945) strategy. Also, as the textbook sheet indicates, students at this point are also required to interpret the results of their number sentences.

As the last step of the algorithm, students are explicitly required to check their results. As the sentence in the textbook says "Is my answer reasonable?", it is likely that this step is intended not only a mechanical step of an inverse arithmetic operation but also referring to the connection between the original word problem and the answer.

China

Since during the last two decades the East-Asian countries became more and more successful in international education surveys, studies on Chinese mathematics education started to become more and more common. The textbook we selected for this study is one of the most widely used ones in China, developed and published by the People's Education Press in Beijing. The students' book does not contain a separate chapter for word problems, and the tasks that could be regarded as ones are very different in form from the ones seen in the textbooks of other countries examined, especially concerning the visual and verbal representations of the problem situations. When examining the visual representations in this textbook series, Biró (2019) found that the Chinese textbooks in first and second grade contain almost three times more visual representations that can be termed "essential" (Berends and van Lieshout, 2009) than the Hungarian textbooks examined above.

Figure 8. Explicit teaching of the steps of word problem solving in a Chinese textbook (People's Education Press, 2019, Part 1, p. 79)

In figure 8, the word problem is presented with a question, followed by a cartoon-like picture where the necessary data is told by the children on the picture. The question says: “How many people are there between Little Li and Little Yu?”, while on the picture, the girl, Little Li says: “I am 10th in the queue.” and the boy, Little Yu says: “I am 15th in the queue”.

The steps that students are required to follow are presented in an explicit way as follows: (1) What did we learn? (2) How to solve it? (3) Is the answer correct? Such a presentation in the textbook was found multiple times, always with these three steps of the strategy. In the first step, students are required to find the given data and also the interpretation of the question. The second step of the strategy not only requires choosing an appropriate method for solving the problem, as in Pólya’s second step of problem-solving strategy but also provides an opportunity for developing students' metacognitive strategies. The little girl in the picture comes up with a way of answering the question: “Let’s count, Little Li is the 10th, after her, there is the 11th, 12th, 13th, 14, then the 15th is Little Yu, there are _ people in the middle.” As a reaction to the girl’s idea, the boy says: “I am making a drawing of it.” Here, students have already been presented with two different ways of solving the problem. As the last part of this step, students are asked: “How do you solve it?” which suggests that students are also welcome to find their own way of thinking.

As the last step of the problem-solving strategy, learners are required to check their solution by the question “Is the answer correct?” Even though this question reflects a step for verification, there is no given arithmetic operation for checking the answer, nor any other explicit help for teaching verification. The only explicit form of verification is the solution itself interpreted into a sentence. The sentence is presented as follows: “There are _ people between Little Li and Little Yu.”. Here, students need to fill in the gap with their solution.

Students are invited to follow these three steps multiple times, especially when facing a new type of problem.

Discussion: Using cartoon-like pictures of children discussing the problem, it seems that the interpretation and teaching of these steps are more like a conversation between students, which is a big difference compared to the European or American textbooks. The conversational way the steps of the problem-solving process is presented implies that the application of these steps is not merely mechanical procedure as steps are followed by the students, but a useful way of encouraging them to monitor the path of their thoughts during problem solving.

Discussion

Conclusions

In this study, we explored and compared the way word problems are introduced in elementary mathematics textbooks from Hungary, Russia, Slovakia, Finland, the USA and China. Our main objective was to examine the different problem-solving steps and strategies and whether there is any explicit introduction of a step-by-step algorithm that students are required to follow. First, we revealed an interesting factor in the presentation of such an algorithm in the textbooks of Hungary and Russia, where the first word problems in the students' textbooks are introduced in parallel with the steps of the algorithm that students are required to memorize and utilize. In the other textbooks, the algorithm is blended with the word problem itself. Second, we found that Pólya's (1945) step of "looking back" is adapted in various ways in the textbooks. In some of them, verification is not even introduced at the early stage of teaching word problems, students are only required to word an answer, while other textbooks put an emphasis on the step of checking the answer.

Another interesting finding that could be the object of further studies is how the problem-solving strategies presented in the textbooks evoke students' metacognitive abilities. While textbooks from Hungary or Russia provides a strict step-by-step algorithm that is more like a checklist, the problem-solving strategy in the Chinese textbook foreshadows a conversation-like setting where students are invited to participate and their way of thinking with peers, which can possibly play a huge role in developing metacognitive thinking.

Limitations

Our study is primarily an exploratory one, where we aimed to reach textbooks that are widely used in a given country, but that does not mean that the results can be generalized in regard of the countries chosen. This limitation especially applies to the United States, where the variety of textbooks is much larger than it is in the Eastern European countries.

Further research questions

Since the main purpose of any research on mathematics education is providing sound and valid arguments on how to better develop students' mathematical thinking and attitudes, textbook comparison research should be further strengthened by classroom observations and objective assessment practices. Thereby the role elementary mathematics textbooks play in shaping students' minds and personalities can be investigated by means of methodological triangulation. Collecting further data from teachers and students can bring further evidence on how textbooks fulfill their roles as educational tools employed for the purpose of fostering students' word problem solving skills and strategies.

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