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VISUAL REPRESENTATION OF WORD PROBLEMS WITH AN AUGMENTED REALITY APPLET

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Abstract: Word problems are one of the most commonly used problems in mathematics education. Though they present a great challenge for pupils, as more than a simple application of arithmetic is required. The successful problem-solving process often depends on a correct understanding of the situation described. One of the steps in the problem-solving process that may help pupils understand the context of a situation is creating a visual representation. This can be achieved using digital tools, such as augmented reality. The aim of this paper is to investigate the possibilities of using a digital applet that has been created. The analysed were 58 word problems submitted by prospective primary school teachers who were tasked to design word problems for which the applet could be used. The analysis was conducted using qualitative analysis and descriptive statistics. The results indicate that the applet can be used when visualising various arithmetic word problems in primary mathematics education.

Key words: mathematics education, teacher training, word problems, augmented reality, visualization

1. Visualisation in Solving Word Problems

Word problems (WPs) are commonly used in mathematics education as they can potentially connect the content of school mathematics with real-life situations and the experiences of pupils. Due to their complexity, they are often considered one of the most challenging tasks within primary mathematics education. The successful WP solving process requires text comprehension, followed by creating a mathematical model, applying mathematical procedures to solve the created equations, checking the adequacy of the results, and presenting the solutions (Verschaffel et al., 2000).

To create and solve a mathematical model, pupils should develop an adequate mental representation of the problem situation, thus understanding the problem. Understanding of a problem situation proves to be one of the most frequent difficulties in solving WPs (Khatib et al., 2025; Pearce et al., 2013). Understanding can be seen as creating an internal representation of the situation, mostly in visual mode. In cases where internal representation is missing, the external visual representation may help students construct a mental model (Jitendra & Woodward, 2019) and support their learning of mathematics (Schoenherr et al., 2024). Therefore, it is important that students learn about visual representations from an early age (Csíkos et al., 2012).

Word problems supported by visual aids may enhance students' performance in the solving process (Ehrhart et al., 2024; Şahinkaya et al., 2024; Scheiter et al., 2010; Wang et al., 2022). The increase in the number of correct solutions can also be achieved when students illustrate a word problem situation themselves (Purcar et al., 2024), and this may be more effective than when the visual aids are generated by someone else (Wong, 1993). Notably, the visual representation of the problem situation should be accurate to increase the likelihood of arriving at the correct solution (Boonen et al., 2014).

The visualisation of word problems can be achieved using different techniques, which can be depicted in various ways (Schoenherr & Schukajlow, 2024). One form of visualisation in mathematics education is dynamic visualisation, which is characterised by the presence of sequential changes in

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time (H.-K. Wu et al., 2015). Dynamic visualisation was generally found advantageous compared to static visualisation (Berney & Bétrancourt, 2016; Höffler & Leutner, 2007), although dynamic visualisation may not be superior to static visualisation in the case of word problems (Ehrhart et al., 2024).

Dynamic visualisation is commonly achieved using computer-based products such as videos, animations, and dynamic software, allowing for interactivity. One of the dynamic environments enabling visualisation and interactivity is augmented reality technology.

1. 1. Augmented Reality and Solving Word Problems

Dynamic visualisation is commonly achieved using computer-based products such as videos, animations, and dynamic software, allowing for interactivity. One of the dynamic environments enabling visualisation and interactivity is augmented reality technology.

Augmented reality technology (AR) is known for its ability to combine real-world information with digitally rendered graphics (Aukstakalnis, 2016). AR is commonly used to visualise geometric concepts (Hnatová et al., 2024); however, it can also be applied in other areas of mathematics education. Particularly in solving word problems, the research suggests three forms of applying AR: to scaffold the solving process of students by being paired with video modelling (Wu, 2023), to improve students' understanding of the word problem by embedding word problems into AR (Tsuei & Chiu, 2021), and to enhance word problems with external visualisations of given variables, helping students to perform the calculations (Ivonne et al., 2020; Mokriš et al., 2023).

Because the research suggests a need for more computer-assisted programs to enhance students' problem-solving skills (Xin et al., 2023), the present study focuses on applying augmented reality to solve word problems. Particularly, the study aims to highlight the feasibility of the digital tool for creating external visualisations.

2. Methods

The aim of this study is to investigate the use of a designed applet supporting augmented reality technology in solving word problems at the primary school level. This led to the following research question: *How can the designed digital tool be employed in solving word problems, and what kind of word problems can it be used for?* To answer this question, prospective primary school teachers were surveyed for their ideas for the designed applet, which were collected and underwent content analysis.

2. 1. Material

The focus of the study was to investigate didactical use of a designed applet supporting augmented reality. The applet was created in GEOGEBRA 5 software. The applet illustrates cylinders that can be coloured using white, blue, and red colours, such that the red and blue colours can only be placed in the lower or upper part of the cylinders (see Figure 1).

The interactivity of the applet is achieved through six sliders, which control the number of all cylinders, the number of red cylinders, the number of blue cylinders, and the size of the cylinders. Additionally, the two remaining sliders allow the user to slide the groups of blue and red cylinders to the left and right. Another important part of the applet is the red axis, which assigns numbers to individual cylinders.

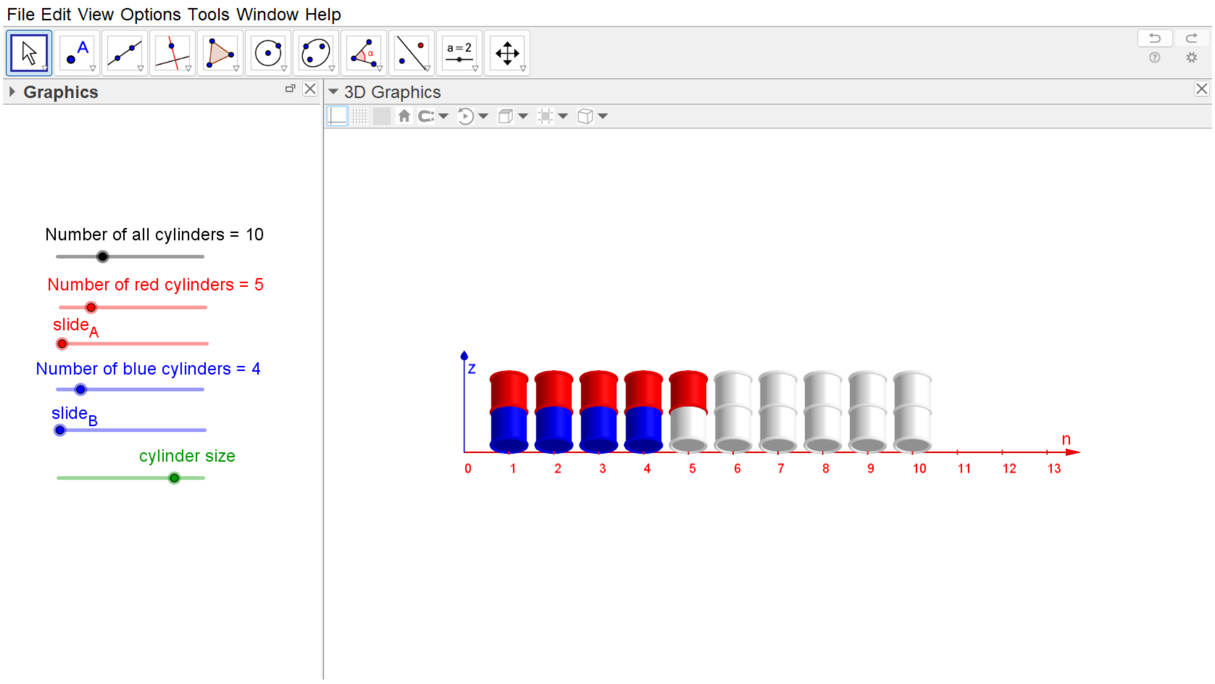

Figure 1. *The applet in the GEOGEBRA software*

2. 2. Participants and Procedure

The participants in the study were 73 prospective primary school teachers in Slovakia, who were asked to create word problems that the applet could be used for. They were initially introduced to the applet running on GEOGEBRA and its functionality to become familiar with it. Since then, they have had full access to the applet, and they could work with it while creating corresponding word problems. Participants were given approximately one month to develop word problems, which were subsequently submitted online.

After receiving the word problems, a qualitative analysis was conducted. Word problems were analysed in two steps. All problems were checked to ensure they were relevant to the applet. Word problems that complied with the requirements were next analysed for the content area and coded based on the identified mathematics topic.

3. Results

From the total of 73 submitted word problems, 15 were rejected for further analysis as they either did not describe the use of the applet or the word problems were not relevant for primary mathematics education. The remaining 58 word problems were coded and further analysed. The collected data showed multiple ways of using the proposed applet in primary mathematics education (see Figure 2).

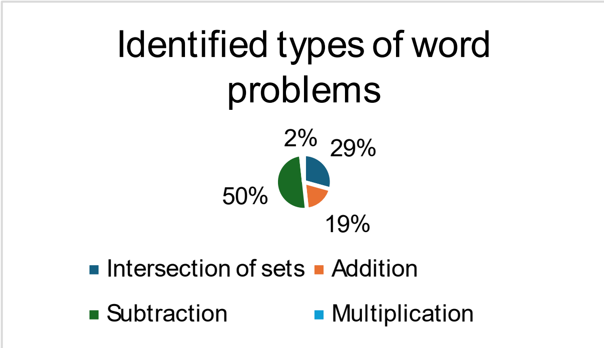

Figure 2. *The types of word problems submitted by participants*

The addition and subtraction problems were further analysed based on the situation described (Riley et al., 1984), and coded for combine, compare, change, and equalise problems (see Table 1).

Table 1. *Categories of addition and subtraction problems detected (Riley et al., 1984)*

Situational context	Unknown	Frequency	Special subcategory	Frequency
COMBINE	Combined value unknown	6	a+b+c	2
	Subset unknown	9	a-b-c	3
COMPARE	Compared value unknown	2	a+b+c	1
	Difference unknown	2	×	×
CHANGE	Result unknown	14	2a-b-c	2
			a-b-c	3
	Change unknown	4	×	×
	Start unknown	×	×	×
EQUALIZE		3	×	×

3. 1. Examples of Collected Word Problems

This section illustrates several examples of applet applications for diverse types of word problems. Because of the relatively large number of problem types that have been identified during the coding procedure (15), only some are described here.

The intersection of sets word problems proposed by participants mostly aimed to find the number of common elements in two sets. These problems were discerned based on whether the conjunction of two groups or the universal set was described by the problem.

Problem 1: *The classroom consists of 11 pupils. Nine pupils own a dog; five pupils own a cat. How many pupils own a dog and a cat?*

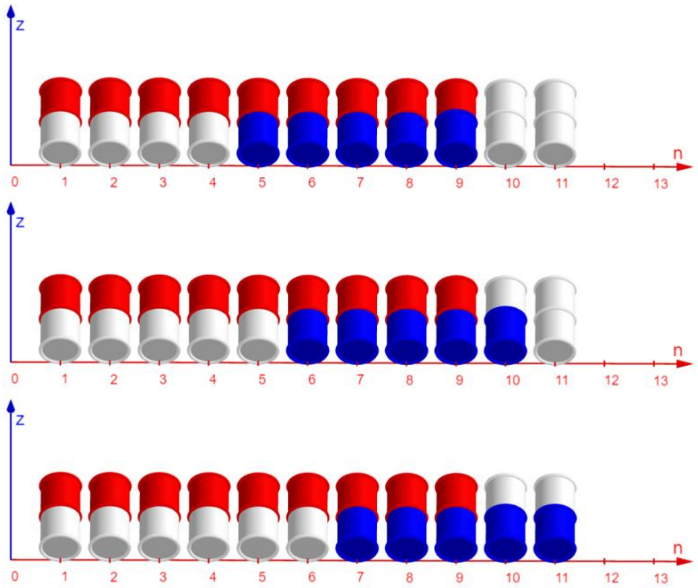

Figure 3. *Graphical representation of Problem 1*

The stated problem defines two groups that may have some elements in common (see Figure 3). The first picture illustrates a scenario in which five pupils have two animals (red and blue cylinders), while two pupils have none (white cylinders). In the second picture, four pupils have two animals (red and blue cylinders), and one does not have any (a white cylinder). In the third picture, all pupils have some animals, and three have both animals. Besides asking to find the number of common items, some of the problems received asked to find the difference between quantities in two sets (e.g. *How many pupils have only a dog?*), which can be determined from the applet based on the number of cylinders in one colour.

In the case of addition and subtraction word problems, the modelling process differs based on the specific type of problem (as distinguished in Table 1).

Problem 2: *The uncle harvested 7 kg of apples and 5 kg of pears. How many kilograms of fruit did he harvest together?*

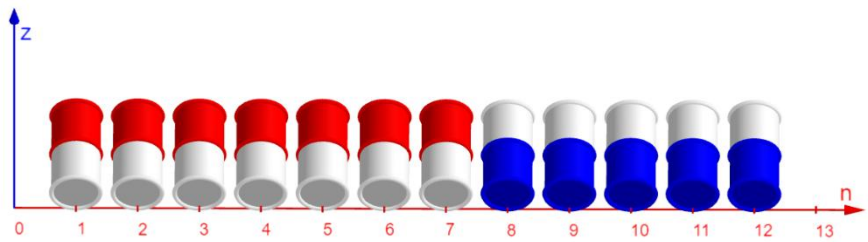

Figure 4. *Graphical representation of Problem 2*

The applet illustrates the combination of two quantities, allowing the total number of fruits to be determined by reading the number line at the bottom of the visualisation. Similarly to Problem 2, the applet can be used to combine three quantities.

Problem 3: Adam has 4 euros, John has 3 euros, and Bill has 2 euros. How much money do they have together?

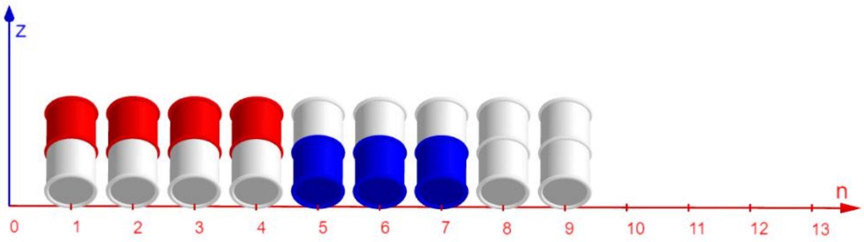

Figure 5. *Graphical representation of Problem 3*

Word problems with three addends can be modelled by the applet, where each addend is illustrated by a different type of cylinder, specifically red-white, blue-white, and white (see Figure 5).

Problem 4: *John is eight years old; Mary is four years older. How old is Mary?*

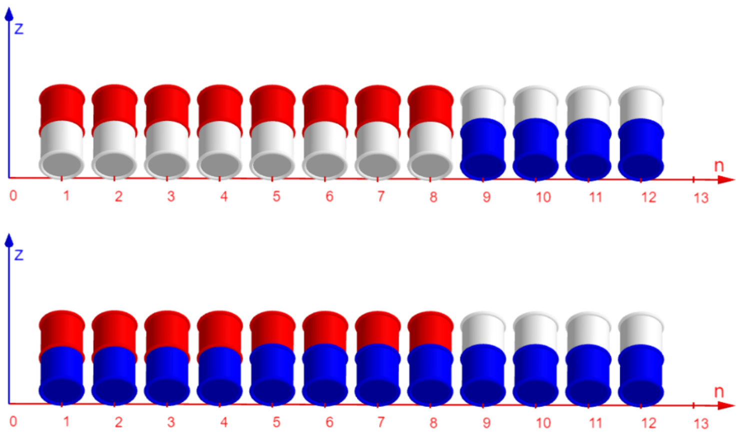

Figure 6. *Graphical representation of Problem 4*

A comparison of two quantities can be visualised in two ways (see Figure 6). The user may either visualise the difference stated by the problem or model the second quantity by adding blue cylinders until the two quantities differ by a constant given by the problem. Then, the second quantity can be read from the number line.

Problem 5: *Peter and Steve counted their toy cars. Peter counted eight cars, while Steve counted six. How many more cars does Peter have than Steve?*

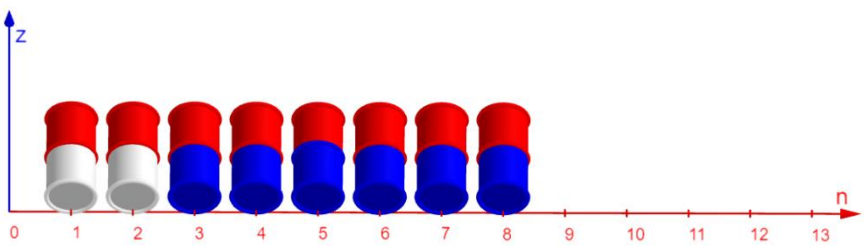

Figure 7. *Graphical representation of Problem 5*

When two quantities are modelled by red and blue cylinders, the difference between them is visualised by white half-cylinders (see Figure 7). Moreover, by dragging the group of blue cylinders to the right, the number of white cylinders can be determined by the number line.

Problem 6: *Pupils formed two lines, each with five pupils. How many pupils were there?*

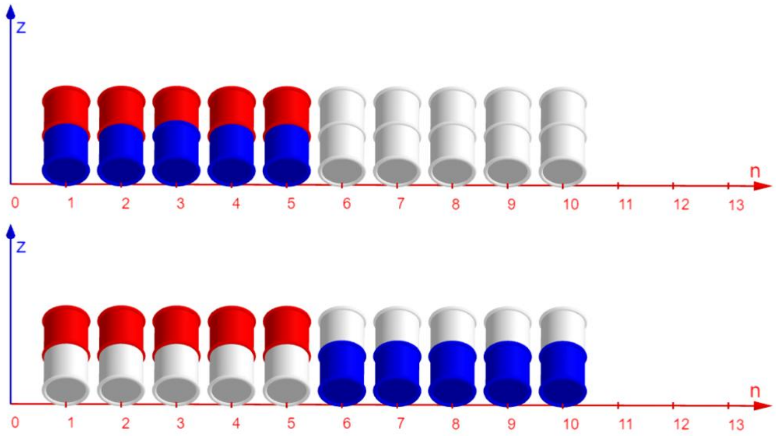

Figure 8. *Graphical representation of Problem 6*

Another way to use the applet is to solve problems involving multiplication by two. In this case, the multiple of two is visualised by having the same number of red and blue half-cylinders organised on top of each other (see Figure 8). Similarly to the addition problems, the multiples of 2 can be determined by moving one set of half-cylinders such that none of the cylinders is red and blue. Finally, the total number is determined by the number line.

4. Conclusion

The present study contributes to the existing research on the application of augmented reality in primary mathematics education. The areas where augmented reality has been applied most often are geometrical shapes (Ahmad & Junaini, 2022; Andrea et al., 2019; Demitriadou et al., 2020; Flores-Bascuñana et al., 2020; Gecu-Parmaksiz & Delialioglu, 2019; Hnatová, 2024; Hwang et al., 2021; Koparan et al., 2023; Mokriš et al., 2024; Yousef, 2021), and numbers and arithmetic operations (Afnan et al., 2021; Drljević et al., 2022; Ivonne et al., 2020; Lazo-Amado et al., 2022; Rebollo et al., 2022).

The results of the present study demonstrated that the applet can be utilised to solve word problems that require multiple mathematical operations, which may benefit learners, as primary school students often struggle with word problems (Vessonen et al., 2024). From Table 1, the applet can be applied to all kinds of addition and subtraction word problems, not excluding the "change–start unknown" type, even though none of the prospective teachers created such a word problem. This implies that participants have seldom encountered such problems, suggesting that their more frequent incorporation in teacher training would be beneficial.

To use the applet as an effective educational intervention, the high quality of the instruction should be attained (Vessonen et al., 2025). In the case of the presented applet, the requirement for correct use is to facilitate students' contextual understanding of the problems, which necessitates the application of a proper text comprehension strategy. One way to implement the applet in primary education is by combining it with a dialogic teaching style (Zhang et al., 2025). As the designed applet is used to visualise quantitative information from word problems in a schematic representation without incorporating the entire word problem, the use of the applet may lead to the split-attention effect (Wang et al., 2022). Therefore, it is suggested to use one's own visualisation in a paper-and-pencil format to facilitate the correct problem-solving process.

The actual use of the applet in solving word problems is at the discretion of the teacher. Teachers sometimes base their choice of a concept representation (visualisation) on their personal preferences (Boonen et al., 2016), which may be determined by their skills (Özsoy, 2018). Fortunately, the research indicates that teachers are interested in using modern methods to facilitate the solution of word problems (Khatib et al., 2025). On the other hand, some prospective teacher see gaps in their readiness to use digital tools in education (Lipták, 2023). Therefore, the successful implementation of digital tools in mathematics education requires thorough teacher training focused on digital technology and its effective utilisation.

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