Arithmetic learning with the use of graphic organiser

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Abstract. For this study, Zollman’s four corners-and-a-diamond mathematics graphic organiser embedded with Polya’s Problem Solving Model was used to investigate secondary school students’ performance in arithmetic word problems. This instructional learning tool was used to help students break down the given information into smaller units for better strategic planning. The participants were Year 7 students, comprised of 21 male and 20 female students, aged between 11-13 years old, from a co-ed secondary school in Brunei Darussalam. This study mainly adopted a quantitative approach to investigate the types of differences found in the arithmetic word problem pre- and post-tests results from the use of the learning tool. Although the findings revealed slight improvements in the overall comparisons of the students’ test results, the in-depth analysis of the students’ responses in their activity worksheets shows a different outcome. Some students were able to make good attempts in breaking down the key points into smaller information in order to solve the word problems.

1. Introduction

Solving words problems plays a significant role in the current trend of Mathematics education, especially in solving those of real-life situations. It is important for students to build strategic cognitive skills for solving word problems, such as to understand a problem, to apply an appropriate method of solution and skills to relate abstract information [1]. Teachers could provide opportunities that encouraged pupils to model, to describe and to apply Mathematics understanding in appropriate and efficient ways [2, 3].

Problem solving was recommended as means in developing mathematical thinking, and referenced it as a planned action or series of actions performed to aid in the discovery of a solution [4]. Research studies supported that learning by understanding encouraged longer information retention thereby becoming a better problem solver as compared to learning through memorising [5]. Using non-routine based problems in problem solving are the most suitable example to real-life processes, because it does not follow a standard algorithm for extracting and representing the given information [6]. Instead, it provides students with opportunities to use prior knowledge to solve problem and to develop complex skills though the domains of modification over a period of time, in both cognitive and
metacognitive processes [7, 8]. Additionally, posing students with open-ended mathematical problems will allow them to use alternative solution methods to solve the problems and that can guide them to a correct solution at a different complexity levels [2]. Activities conducted in the classroom should encourage effective strategies, forming the basis for understanding mathematical processes and concepts [9].

Solving mathematical problems requires students’ comprehension and understanding before they are able to apply appropriate strategies to solve the problem [10]. However, students who are weak in Mathematics tend to be lacking in mathematical thinking skills [11, 12]. It is crucial to provide students with the opportunities to solve real-life word problems, and this will require students to apply their transient from algorithmic mathematical thinking to solve problem better [13].

1.1. Integrating the Pólya’s problem solving model

George Pólya was a Hungarian mathematician responsible for many well-known conjectures and theorems. Pólya suggested four stages of a problem solving model aimed at helping student learners to formulate logical thinking; to apply reasoning skills and develop understandings on how to connect information from concrete to abstract. The problem solving process was systematised into four stages: understand the problem being posed, devising a plan, carry out the plan and looking back [14]. According to Khalid [15], Pólya argued that for students to understand Mathematics, their experience must be consistent with the way Mathematics is done. There is no particular approach that teachers can use. Different subject requires different kinds of approaches. In this study, Pólya’s problem solving model was used as a tool as part of the strategy to examine the development of Mathematics word problems in students. Teachers are encouraged to use instructional techniques in order to improve students’ attitudes towards the learning of Mathematics [16–19].

1.2. Graphic organiser embedded with Pólya’s problem solving model

Zollman [20–22] introduced a four corners-and-a-diamond mathematics graphic organiser embedded with Pólya’s four steps problem solving model (refer to Figure 1) to elementary and middle school students in solving algebraic word problems. The graphic organiser used was a modification from the four-squares writing graphic organiser modelled by Gould and Gould [23]. The findings from Zollman’s studies revealed that the students developed positive attitude and higher confidence level towards solving Mathematics word problems with the use of the graphic organiser. The use of visual representation in a graphic organiser as a medium to aid students in understanding the word problems might eventually improve students’ conceptual knowledge [24].

![Figure 1. Zollman’s graphic organiser embedded with Pólya’s Problem Solving Model (taken from Zollman [20–22]).](image-url)
2. Methodology
This study mainly adopted a quantitative approach to investigate the types of differences found in the arithmetic word problem tests. A diagnostic test consisting of pre- and post-tests were used to compare and analyse the students’ performances quantitatively. The Zollman’s four corners-and-a-diamond mathematics graphic organiser (Figure 1) embedded with Pólya’s Problem Solving Model (hereafter referred to as ZPPSM) was used as the instructional tool in problem solving. The ZPPSM was introduced to provide an alternative tool that would help students improve their Mathematics achievements. We anticipated that the students might be able to break down the information into smaller units for better strategic planning. The research question for this present study is “What differences, from the use of ZPPSM, can be found in the students’ arithmetic word problem tests results?”

2.1. Participants
The sample for this study was Year 7 students from a co-ed secondary school in Brunei Darussalam. There were 21 male and 20 female students, aged between 11-13 years old. The same teacher in the sampled school taught the two classes. The permission to conduct the study was approved by the Department of Schools, Ministry of Education. And all participants gave informed consent.

2.2. Procedure
Both classes took part in the pre and post-tests. The study was conducted in a normal classroom setting with students sitting in paired groupings in order to collaborate and solve a mathematical word problem. In addition, it was conducted in the afternoon, for 3 days with a total of 7 lesson periods. Each lesson period was 30 minutes. The pre-test took approximately an hour for the students to answer on Day 1. This artefact was collected as evidence to provide details on the students’ problem solving performance, while simultaneously evaluating the common factors in solving arithmetic test items. The written test paper consisted of 17 simple numeral word problem questions. On Day 2, the students engaged in a group activity and used the ZPPSM to solve the given word problem as seen in Figure 2 below. A total of 30 minutes was allocated for the Mathematics computation work. The first 20-25 minutes was allocated for the briefing of the rules and regulations for the activity task. The artefacts of the word problem was analysed according to the various responses from the students’ work. All participants were allowed to use the electronic calculator during the activity. The group activity was done to investigate if the use of ZPPSM showed any significant differences in the students’ performances between the arithmetic tests. The activity continued on the final day and a post-test was then administered.

Activity: A day out to the Night Market with a budget of $20
In this activity, each student is given a sum of $20 to purchase any items listed on the piece of worksheet attached. The student must fully make use of the amount given. The student is allowed to choose a minimum of two items, and a maximum of 5. There is no limitation on the chances of having an item being repeatedly selected. However, you are required to show or write the possible mathematical calculation(s) that would match the criteria stated. That is, you will have to show the number of possibilities on how to obtain an answer of $20 in the total sum. The items that were provided to you for the selection, ranged from a price tag of $0.50 to $4 dollars.

Figure 2. A word problem used in the ZPPSM group activity.

3. Results and Discussions
A paired samples t-test conducted on the sample group that used ZPPSM indicated that the scores were not significant for the post-test sub-scale ($M=12.73, SD=2.64$), in comparison to the pre-test sub-scale ($M=12.41, SD=1.96$), $t(40)=0.94, p=.353$. Therefore, we conducted a comparison analysis of the sample that uses ZPPSM with another group that did not practice the use of ZPPSM.

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The score difference between sample groups that was taught with ZPPSM and the control group are shown in Table 1. The scores of students between the tests were higher for the group taught with ZPPSM ($M=12.73$, $SD=2.64$) than the group without ZPPSM ($M=11.40$, $SD=1.78$), $t(69)=2.73$, $p=.008$, $d=0.605$, suggesting that the use of the ZPPSM would have an effect on the students’ results. In particular, the findings suggested that students who were exposed to ZPPSM tended to perform better. The tests had a Cohen’s $d$ value of 0.60, indicating a moderate effect between the tests. A $p < 0.05$ stated differences between tests, mainly that the students’ results in the post-test were slightly higher as compared to the pre-test.

Table 1. Independent t-test between groups (with and without ZPPSM).

|                  | N  | Mean  | SD   | t    | df  | Sig. (2 tailed) | Cohen’s d |
|------------------|----|-------|------|------|-----|----------------|-----------|
| Post-test with ZPPSM | 41 | 12.732| 2.637| 2.728| 68.624 | 0.008          | 0.605     |
| Post-test without ZPPSM | 47 | 11.404| 1.777|      |      |                |           |

Table 2 shows the results of the Cronbach alpha of each item of the arithmetic pre-test instrument with a reliability coefficient of 0.607, whilst the post-test Cronbach’s alpha value of 0.697 was obtained for the group that used the ZPPSM. This increase in value between both groups’ reliability tests demonstrated a moderate internal reliability and hence the test was reliable to be carried out for the main study.

Table 2. Instrument item reliability test used in the tests.

| Instrument                   | No. of Students | No. of Items | Cronbach alpha and reliability coefficient |
|------------------------------|-----------------|--------------|------------------------------------------|
| With ZPPSM                   |                 |              |                                          |
| Pre-test                     | 41              | 18           | 0.607                                    |
| Post-test                    | 41              | 18           | 0.697                                    |
| With & Without ZPPSM         |                 |              |                                          |
| Pre-test                     | 88              | 18           | 0.625                                    |
| Post-test                    | 88              | 18           | 0.647                                    |

A cross-tabulation of the paired sample t-test was conducted on the students’ attempts for the pre-test items. The results showed that among the 19 items of word problem questions allocated, there were 5 significant items that had a $p$-value of less than 0.05. The 5 items are listed in Figure 3, indicated as Q3b, Q4b, Q5, Q14 and Q17, whilst the remaining 14 items showed little significant difference before and after the tests.

**Compare and find solution:** (Q3) Suzi is 12 years older than Fatin, and 7 years younger than Jenny. Jenny is 19 years old. (a) How old is Suzi? (b) How old is Fatin?

**Known difference, possible ways:** (Q4) Find the solution of a 3-digit number and a 2-digit number whose difference is 23. Write out two possible sets of solutions. (a) Solution answer 1 (b) Solution answer 2

**Unknown total (visual/mental computation):** (Q5) Some children stood in a line. Hasya is thirteen from one end and fifth from the other end. How many children are there in the line?

**Compare problems, difference unknown:** (Q14) Raj has 73 balloons and Matt has 42 balloons. How many more balloons does Raj have than Matt?

**Known difference and total sum, but unknown initial value:** (Q17) Some money is shared between Ali and Shai, so that Ali gets $5 more than Shai gets. The money to be shared is $47. How much money does Ali and Shai get?

**Figure 3.** Descriptions of the identified significant question items.
Presented in Table 3 are the descriptive statistics obtained from the students’ responses. The results indicated the increase in percentages for all the items with the correct answers in the post-test. Item Q3b showed a higher score in correct answer in the post-test (27.9%) when compared to the pre-test (12.2%). Meanwhile, Q4b showed a 9% increase in students obtaining correct answers and there was a reduction of 18% for ‘No attempt’.

Table 3. Descriptive statistics of students’ attempts on the arithmetic test items given (N = 41).

| Item | Pre-test (%) | Post-test (%) |
|------|--------------|---------------|
|      | Correct Answer | Attempt | No Attempt | Correct Answer | Attempt | No Attempt |
| Q3a  | 36.6         | 61.0       | 2.4        | 39.5         | 55.8    | 0.0        |
| Q3b  | 12.2         | 80.5       | 7.3        | 27.9         | 67.4    | 0.0        |
| Q4a  | 9.8          | 63.4       | 26.8       | 18.6         | 58.1    | 18.6       |
| Q4b  | 7.3          | 56.1       | 36.6       | 16.3         | 60.5    | 18.6       |
| Q5   | 4.9          | 87.8       | 7.3        | 16.3         | 79.1    | 0.0        |
| Q14  | 78.0         | 12.2       | 9.8        | 86.0         | 9.3     | 0.0        |
| Q17  | 12.2         | 70.7       | 17.1       | 16.3         | 79.1    | 0.0        |

From Table 3, among the five items identified, item Q4b showed a drastic drop of 18% for ‘No attempt’ as compared to the pre-test, indicating that most students attempted to answer that question. Comparing both the scales, the students’ no attempt decreases and the correct answer increases in the post-test. Thus displaying a significant difference in the students’ effort to answer, especially in solving items Q3b, Q5, Q14 and Q17 during the post-test. In summary, the results obtained for the 5 items shown in Table 3 demonstrated the students’ tendency to perform better in the post-test. To support the findings further, an analysis of the students’ written attempts was made. The results in Table 4 are based on the methods preferred by the students in the tests. The students’ algorithmic answers and workings were thematically categorised and analysed.

Table 4. Percentage of the item methods used.

| Item | Incorrect Methodology | Incorrect Answer | Incorrect Instruction | Correct Methodology and Answer | No written answer or attempt |
|------|----------------------|------------------|-----------------------|-------------------------------|----------------------------|
| Q3a  | 43.9                 | 4.9              | 9.8                   | 36.6                          | 4.9                        |
| Q3b  | 19.5                 | 7.3              | 51.2                  | 12.2                          | 9.8                        |
| Q4a  | 12.2                 | 4.9              | 46.3                  | 9.8                           | 26.8                       |
| Q4b  | 14.6                 | 0.0              | 41.5                  | 7.3                           | 36.6                       |
| Q5   | 22.0                 | 31.7             | 26.8                  | 2.4                           | 12.2                       |
| Q14  | 12.2                 | 0.0              | 0.0                   | 78.0                          | 9.8                        |
| Q17  | 31.7                 | 7.3              | 4.9                   | 9.8                           | 17.1                       |

Note: Other methodologies used for Q5 (Attempt use of diagram = 4.9%) and Q17 (Partial correct attempt = 29.3%).

Items Q3, Q4 and Q17 (refer to the descriptions in Figure 3) shared the same patterns of having the initial value as being ‘unknown’. Item Q3 is a ‘compare and find solution’ question requiring the participants to highlight the keywords written on the word problem and be able to solve using the information given. For item Q3a, 43.9% of the population was shown to have used the ‘incorrect methodology’ to solve the problem. However, 36.6% succeeded in using the ‘correct methodology’ and were able to obtain the ‘Correct answer’. In order to solve Q3b, the answer to item Q3a is
required. If a student obtained an incorrect answer in Q3a, it will cause the final response in Q3b to be incorrect. Hence the high percentage (51.2%) observed for item Q3b for the ‘incorrect instruction’ and 19.5% on the ‘incorrect methodology’ used.

Item Q4 was a ‘known differences’ question that had ‘multiple possible ways to obtain the correct answer’. Items Q4a and Q4b shared the same type of questioning techniques. Item Q4a showed that ‘incorrect instruction attempt’ comprised of 46.3% of the population while ‘no written answer or attempt’ was 26.8%. Item Q4b showed 41.5% of ‘incorrect instruction’ attempt and 36.6% of ‘no written answer or attempt’. Hence, Q4 item showed a high percentage of students that used the methodologies ‘incorrect instruction’ and ‘no written answer or attempt’.

Item Q5 was an item that required participants to find the ‘unknown total’ either through visual or mental computation and conceptual understanding of Mathematics. For this item, the results showed few participants were able to obtain the ‘correct responses’ (2.4%) and only few attempts to solve on ‘use of diagram’ (4.9%). Amongst the participants, 31.7% of the attempts were due to ‘incorrect answer’, 22% on ‘incorrect methodology’ and 26.8% from ‘incorrect instructions’. Therefore, the findings revealed that a strong relationship of failed attempts were due to the inability to use a pictorial concrete diagram to help the participants to visualise.

Simple comparison problems required the students to find out the differences between two given values, and 78% of the sample was able to obtain ‘correct answer’ responses with ‘correct methodology’ for item Q14. Consequently, it shows that the students were able to answer comparative questions when required to find the unknown differences between the initial and final values.

Item Q17 from Figure 3 is a word problem adopted from Stacey and McGregor [25] and Stacey [13]. It is a question that requires students’ understanding, before attempting. The item Q17 was provided with information such as, ‘total sum’ and ‘known difference’ but not the ‘initial unknown’ value. The participants were required to find out the ‘unknown’ value as a pre-requisite task. As shown in Table 4, majority of the participants could either attempt with ‘incorrect methodology’ (31.7%) or to ‘partial attempt with correct responses’ (29.3%).

In general, the analysis of the 5 items enabled us to realise that pictorial concrete representation could aid students’ understanding in answering a word problem. The students also achieved higher success in comparative questions. Various attempts of problem solving methodology could compromise the lack of mathematical understanding, especially in the case of ‘unknown initial’. In addition, the students either use ‘incorrect instruction or methodology’ leading to incorrect solution and failure to understand. However, the findings did show there were higher rate of attempts by the students to obtain correct answers in the post-test and they scored better in the post-test as compared to the pre-test. Therefore, the use of ZPPSM has improved the students’ ability to boost their mathematical knowledge and constructive experiences in benefitting them to solve problems better.

3.1. Analysis from the ZPPSM activity sheet
Most students worked in pairs, except for the Group 1 student who had to work individually due to the odd number of students’ attendance that day. From Table 5, there were a total of 7 groups of students with correct responses of zero (3 for Group 1 and 4 for Group 2), and this consisted of 31.8% of the sample. Group 2 had 12 correct answer responses (54.5%) as compared to Group 1 (45.5%).

| Table 5. The frequency of students’ correct responses using ZPPSM during the activity. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Class           | Number of correct responses | Total correct responses |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Group 1         | 0   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|                 | 3   | 0   | 1   | 0   | 1   | 1   | 0   | 1   | 1   | 1   | 1   | 0   | 10  |
| Group 2         | 4   | 3   | 0   | 1   | 0   | 0   | 0   | 0   | 1   | 0   | 1   | 1   | 12  |
The group that showed a high success rate in obtaining correct responses had a much more organised key points written on the ZPPSM (refer to Figures 4, 5 and 6). Therefore, the use of the ZPPSM aided the students to break down the information into small pieces (refer to Figures 5 and 6).

Figure 4. Samples of correct solutions on the activity sheet.

Figure 5. Sampled student 1 artefact with the use of ZPPSM.

Figure 6. Sampled student 2 artefact with the use of ZPPSM.

Figure 7. Samples of incorrect student responses written on the activity sheet.
The three different artefacts shown in Figure 7 demonstrated the students’ ‘incorrect instruction’ attempts. For example, the first artefact Figure 7a), illustrated the ‘incorrect instruction’ sample in which the $7 and $8 values do not exist on the activity sheet. The artefact Figure 7b) showed that the student obtain the correct answer but using an incorrect instruction. This is because the student was supposed to select at least two different cost items; but only selected the same $4 items to produce a total sum of $20. Thus, it was categorised as the incorrect instruction attempts. The incorrect response shown in Figure 7c), having a total sum of $5 was insufficient to match with the acquired total amount of $20. In reference to the students’ written attempts on the ZPPSM worksheets demonstrated that the group did not fully utilise the usage of the ZPPSM, and produced few correct responses. This may also be in part the limitation of this study since the students were only exposed to one cycle on the use of ZPPSM. Nonetheless, the findings above provided a positive grounding in the use of ZPPSM as an effective strategic tool to help students learn arithmetic word problems. The strategic ZPPSM tool would promote transient Mathematics thinking through the active organising and re-organising of concepts and processes [9, 11, 13, 15, 26].

4. Conclusions
Khoo et al. [10] suggested that the Zollman’s graphic organiser instructional tool to be an effective tool in helping students to solve problems and develop a positive attitude towards solving Mathematics word problem. Comparing the activity artefacts, it can be concluded that the students who practice Mathematics problem solving with the use of ZPPSM made attempts to break down key points into smaller information. Those students who showed legible and orderly work with ZPPSM tend to have higher outcome success than those who did not use ZPPSM (referring to Table 5 and Figures 4-7). Despite the moderate ‘effect size’ of using ZPPSM, it did indicate that the arithmetic post-test result was of higher reliability. However, we do realise that the two classes involved in this study, especially from only one secondary school, were insufficient in terms of providing further insights into the students’ learning. Yet, the use of ZPPSM has shown to be effective in helping students improve their Mathematics results by breaking down information into smaller chunks [10]. It may be beneficial to introduce the ZPPSM as a strategic tool to student, providing them with opportunities to learn and to develop their understandings.

The analysis using paired sample t-test on the arithmetic tests indicated that the students had difficulties with questions having ‘unknown initial’ variables. With reference to the above analysis, the students could perform ‘Join’, ‘Separate’ and ‘Part-whole’ kinds of arithmetic questions with ease, except the question items with ‘unknown initial’ as listed in Figure 3. The students will require more effort to find the solutions for this type of word problems. Moreover, Stacey [13] found that the basic difficulties in problem solving approach were due to the idea of unknown that appears together with the given task, regardless if it is transformative thinking or not. Meanwhile, the results in Table 4 indicated that students with ‘no written answer or attempt’ had a high tendency towards ‘incorrect instructions’ leading to ‘incorrect methodology’ and thus, ‘incorrect answer’ obtained. Therefore, by providing students with opportunities to learn and willingness to attempt would develop potentials to improve. Nevertheless, strategic tools such as the ZPPSM used in this study will benefit students’ brainstorming process with its visual representation and is believed to resolve students’ difficulties in solving word problems; and to provide opportunities that encourage students to develop positive attitudes towards solving Mathematics [10].

The findings in this study revealed that the students’ performance was slightly better in the post-test when compared to the pre-test. However, there were some students who still faced difficulties in familiarising themselves with the use of the ZPPSM. The findings also indicated that the student groups that obtained the low marks failed to optimise the use of the ZPPSM hence leading to failures to follow instructions given and to obtain correct responses. In addition, the underperforming students would require more time to fill the empty boxes in the graphic organiser; and thus a prolong exposure
of the ZPPSM would better benefit and allow the students to acquaint themselves with the four stages of Pólya’s problem solving model.

This study has shown that the use of the ZPPSM improved the students’ results. Therefore, it is recommended that teachers or educators to consider using the ZPPSM in their lessons. It is advisable that the teacher provides more time and practice for their students to familiarise themselves with the use of ZPPSM as a strategic instructional tool. The teacher should also be well trained on the applications of the Pólya’s problem solving model well before implementing them to their lessons.

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