Using a Self-Explanation Strategy to Solve Mathematical Word Problems

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The present study examined how a metacognitive strategy known as self-explanation helps elementary school children solve mathematical word problems. Fifth and sixth graders were assigned to either a self-explanation group or a control group. Students in each group performed mathematical word problem tests and a transfer test. The results showed that fifth graders in the self-explanation group outperformed those in the control group on mathematical word problem tests. In addition, high self-explainers who generated more self-explanations relating to deep understanding of worked-out examples outperformed low self-explainers on both mathematical word problem tests and the transfer test. The self-explanation effect is discussed.

Key words : elementary school children, mathematical word problem solving, self-explanation, worked-out examples

1. INTRODUCTION

Many researchers have focused on the effects of metacognitive strategies in academic domains. Metacognitive strategies mean that students apply reflective thinking to problem solving or memorization tasks. It is well known that there are a variety of metacognitive strategies, for example, self-explaining, self-questioning, asking questions, answering questions, summarizing, note-taking, and drawing. Recent research has shown that self-explaining is an effective metacognitive strategy across a wide range of academic task domains (e.g.,Aleven & Koedinger, 2002; Chi, 2000; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, de Leeuw, Cniu, & LaVancher, 1994; Renkl, 2002; Tajika, Nakatsu, Nozaki, Neumann, & Maruno, 2007). Students generally improve their performance better when they explain tasks such as expository texts and physics problems to themselves (Bielaczyc, Pirolli, & Brown, 1995; Chi et al., 1989; Renkl, 1997) or when they self-explain their own problem-solving steps (Berardi-Coletta, Buyer, Dominowsky, & Rellinger, 1995; Neuman & Schwarz, 1998, 2000; Tajika et al., 2007). Mathematics education is especially improved metacognitive strategies that get students to learn with greater understanding.

The purpose of the present study was to examine how a metacognitive strategy known as self- explanation helps word-problem solving in elementary school children. Our research explores the effectiveness of self-explanation as a metacognitive strategy in mathematics education for elementary school children. The children in our study were fifth and sixth graders in Japanese elementary schools. Self-explanation is one of the well-established helpful strategies for facilitating mathematical word problem solving. According to Chi (2000), self-explanation re-

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fers to utterances in which students explain the contents during learning to themselves. Self-explanation was postulated as a potential learning activity in trying to understand how students are able to learn successfully from text materials that are incomplete or to learn procedural skill from worked-out examples (Chi et al., 1989). Learning materials often include information gaps or omissions both in the text passages as well as in descriptions of the steps involved in worked-out by examples. Self-explaining is now known as an effective metacognitive strategy that helps students develop deep understanding of complex academic tasks. Researchers have established the benefits of self-explaining across many academic domains for a range of ages and learning contexts. We first provide evidence for the effect of self-explaining by reviewing research on self-explaining mechanics problems and mathematical word problems.

Chi et al. (1989) analyzed the self-explanation which university students generated while studying worked-out examples and solving mechanics problems. They divided students into two groups, high self- explainers and low self-explainers, based on problem solving performance. High self-explainers solved more problems than low self-explainers. They showed that high self-explainers and low self-explainers differed with respect to both quantitative and qualitative aspects of self-explanations. High self-explainers tended to generate a greater number of self-explanations while studying worked-out examples of mechanics problems. They also tended to utter more accurate self-monitoring statements while studying worked-out examples. Chi et al. (1989) found that high self-explainers learned with understanding. They conclude that high self- explainers have specific goals when they refer back to the worked-out examples, such as looking for a method to find the value of a particular force. In contrast, low self-explainers, who initially spend less time studying the worked-out examples, have general goals that require them to reread large portions of the entire problems.

Research on self-explanation has shown facilitative effects in a domain of mathematical problem solving (e.g., Aleven & Koedinger, 2002; Mwangi & Sweller, 1998; Nathan, Mertz, & Ryan, 1994; Neuman & Schwarz, 2000; Tajika et al., 2007). For example, Nathan et al. (1994) examined how the self-explaining process related to learning and subsequent problem-solving performance. They manipulated two kinds of problem-solving task (algebra manipulation tasks versus algebra story problem translation tasks) and two kinds of cognitive load (a high load versus a low load). University students were either prompted or not to self-explain while they generated their own solutions (high load condition) or studied worked-out example solutions (low load condition). They found that self-explaining facilitated test performance in the low load group for the story problem translation tasks but offered only a marginal advantage for the algebra manipulation tasks. Moreover, Aleven and Koedinger (2002) used geometry problems to compare self-explanations emphasizing computer-based instructional environments to instructional methods that did not emphasize self-explanations. Students were trained to self-explain their solution steps for geometry problems within computer-based instructional environments. Aleven and Koedinger (2002) found that 10th-grade students who self-explained their solution steps during problem-solving practice within computer-based environments learned with greater understanding compared to students who did not explain their solution steps.

The function of self-explanation is to actively make sense of the presented learning materials (Chi, 2000). Self-explanation seems to be a constructive activity that engages students in active learning. Self-explanation involves several cognitive and metacognitive processes, which include generating inferences to make sense of uncertain statements relating the problems' surface features to structural features, integrating new information with prior knowledge, and monitoring what the statements refer to (Chi, 2000; Roy & Chi, 2005). As a result, the activity of self-explaining may be cognitively demanding. There is consistent evidence that even university students actually have difficulty engaging in generating a sustained level of high quality self- explanations (Atkinson, Derry, Renkl, & Wortham, 2000). When elementary school children are urged to self-explain each step of worked-out examples of mathematics word problems, they do not spontaneously self-explain their steps.

So, we hypothesized that high self-explainers would solve more word problem and transfer tests than low self-explainers when quality of self-explanation influences students' problem solving processes.

2. METHOD

2.1. Participants

Fifth- and sixth-graders in the public elementary school participated in the experiment. The participants were 52 fifth graders (mean age was 11 years 5 months) and 48 sixth graders (mean age was 12 years 4 months). Twenty-four fifth graders were assigned to the self-explanation group and twenty-eight fifth graders were assigned to the control group. Twenty-three sixth graders were assigned to the self-explanation group and twenty-five sixth graders were assigned to the control group. All of the students had also taken an arithmetic class for the present word problems when they were fourth graders.

2.2. Experimental Design

A 2(grade: fifth grade vs. sixth grade) x 2(group: self-explanation vs. control) between-subjects design was carried out.

2.3. Materials

2.3.1. The Tests Used in the Present Experiment

A total of three kinds of tests were used in the experiment: a pretest, two types of mathematical word problem tests, and a transfer test. All materials were presented in Japanese.

The pretest consisted of two types of four mathematical word problem tests, a type of two elimination problem tests and a type of two decimals problem tests. Each type of word problem test consisted of an easy word problem test and a difficult problem test.

The mathematical word problem test used as a critical word problem test in this experiment consisted of four word problems including elimination and four word problems including decimals.

The transfer test consisted of an 18-item word problem test, adapted from a multiple-choice test used by Mayer, Tajika, and Stanley (1991). It had three kinds of questions. One kind of question was to make a number sentence from a sentence such as, "Taro has 5 more apples than Hanako." Another kind of question was to write down the numbers to be needed to solve such a problem as, "Masao had 500 yen for lunch. He bought a sandwich for 290 yen, an apple for 70 yen, and a milk for 110 yen. How much money did he spend?" The other kind of question was to write down the operations to be carried out to solve such a problem as, "If it costs 100 yen per hour to rent roller skates, what is the cost of using the skates from 1:00 p.m. to 3:00 p.m.?" Students were asked to generate an answer to each question instead of being given a multiple-choice test.

2.3.2. Worked-Out Examples

Worked-out examples used in the

experiment were two types of word problems, which included elimination and decimals. Both types of worked-out examples contained two kinds of word problems, an easy word problem and a difficult word problem.

The easy worked-out example of the word problems including elimination was as follows. "When you buy one entrance ticket and six vehicle tickets in an amusement park, you pay 1700 yen. When you buy one entrance ticket and five vehicle tickets in the amusement park, you pay 1500 yen. How much do you pay for one vehicle ticket?" The easy worked-out example problem had six solution steps and the answer in the self-explanation group. (Step 1) You must answer the cost of one vehicle ticket. (Step 2) When you buy one entrance ticket and six vehicle tickets in an amusement park, you pay 1700 yen. (Step 3) When you buy one entrance ticket and five vehicle tickets in the amusement park, you pay 1500 yen. (Step 4) The relation between these explanations can be expressed with the diagram. (Step 5) As the diagram expresses, the difference between these two lines means one vehicle ticket. (Step 6) You can calculate the cost of one vehicle ticket as 1700-1500. (Answer) The answer is 200 yen (1700-1500=200).

The easy worked-out example of the word problems including decimals was as follows. "Yoshiko makes rubber bands to use in the class for handicrafts. The rubber bands are made from cutting a rubber string with 3.4 meters in 0.4 meters each. How many rubber bands do you have?" The easy worked-out example problem had five solution steps and the answer in the self-explanation group. (Step 1) You must answer the number of rubber bands. (Step 2) You have a rubber string with 3.4 meters. (Step 3) You divide a rubber string with 3.4 meters into 0.4 meters. (Step 4) The relation between these explanations can be expressed with the diagram. (Step 5) You can calculate the number of rubber bands as 3.6÷0.4. (Answer) The answer is 9 (3.6÷0.4=9).

The difficult worked-out example of the word problems including elimination was as follows. "When you get to the roller coaster in an amusement park, one adult costs twice as much money as one child costs. Two adults and three children cost 2100 yen. How much does each of one adult and one child cost?" The difficult worked-out example problem had eight solution steps and the answer in the self-explanation group. (Step 1) You must find the cost of one adult and the cost of one child. (Step 2) One adult costs twice as much money as one child costs. (Step 3) Two adults and three children cost 2100 yen. (Step 4) As the cost of one adult is equal to that of two children, the cost of one adult is exchanged for that of two children. (Step 5) When the relation between these explanations can be expresses with the diagram. (Step 6) Two thousands and one hundred yen mean the cost of seven children (2 x 2 + 3 = 7). (Step 7) One child costs 300 yen (2100 ÷7=300). (Step 8) You can answer the cost of one adult as 300 x 2. (Answer) The answer is as follows: One adult costs 600 yen (300 x 2=600) and one child costs 300 yen.

The difficult worked-out example of the word problems including decimals was as follows. "You have 1.6 liters of honey. Honey weighs 2.4 kilograms. How much does 3 liters of honey weigh?" The difficult worked-out example had seven solution steps and the answer in the self-explanation group. (Step 1) You must find the weight of 3 liters of honey. (Step 2) 1.6 liters of honey weighs 2.4 kilograms. (Step 3) The relation between these explanations can be expressed with a diagram. (Step 4) To find the weight of 3 liters of honey, you must calculate the weight of one liter of honey. (Step 5) When you divide 2.4 liters by 1.6 liters (2.4÷1.6=1.5), you find the weight of one liter of honey is 1.5 kilograms. (Step 6) The relation between these explanations can be expressed with the diagram. (Step 7) The weight of 3 liters of honey is calculated by 1.5 x 3. (Answer) The answer is as follows: The weight of 3 liters of honey is 4.5 kilograms (1.5 x 3 = 4.5).

2.4. Procedure

The experiment had four sessions and was carried out in groups.

In the first session, students took pretests and each of them took 20 minutes. Each pretest consisted of 4 word problems corresponding to a word problem test which was given after a worked-out example had been studied.

In the second session, students in the self-explanation group received two types of worked-out examples, both of which included an easy worked-out example and a difficult one. Before students wrote down their explanations in the blank spaces on the example sheet during self-explaining for each solution step, they were asked about whether they understood a problem solution at each step. When students understood it, they answered "yes" and then wrote down their explanations. When students did not understand the problem solution at each step, they circled the "no" answer in pencil. Then, they were encouraged to write down their explanations about why they did not understand it. Students in the control group studied each of the same word problems including one solution step and its answer. Teachers provided instruction for four worked-out examples of the word problems based on a usual method. Students in the control group were told about how to solve the word problems and were instructed to understand each numerical expression as a solution step towards their answers. It took 40 minutes for students of both groups to take all four kinds of worked-out examples.

In the third session, students in each group took word problem tests that consisted of each of the word problems with a time limit of 40 minutes. These word problem tests corresponded to those used in the second session.

In the fourth session, one month after each word problem test, each student took a transfer test that took 40 minutes.

3. RESULTS

3.1. Results of the Pretest

The prestest consisted of four problems, two easy ones and two difficult ones. The score of each problem was two points, so that the maximum score of the pretest was eight points. The results of the pretest were as follows: The mean score of sixth graders was 11.98 (SD=3.21) in the self-explanation group and 11.58 (SD=2.82) in the control group. The mean score of fifth graders was 7.54 (SD=3.48) in the self-explanation group and 7.86 (SD=2.91) in the control group. There was no difference in each grade between two groups. There was a significant main effect of grade, $F(1, 96)=41.62$, $p<.01$, $\eta^2=.75$. Sixth graders outperformed fifth graders on the pretest.

3.2. Results of the Word Problem Tests

The word problem test consisted of eight problems. Each problem has two parts: one is an algebraic expression and the other is its answer. One point was given to each correct part. As a result, the score of each problem was two points, so the maximum score of the word problem test was 16 points. The results of the word problem test are presented in the left column of Table 1. A 2(grade) x 2(group) ANOVA (Analysis of Variance) was carried out. There was a significant main effect of grade, $F(1, 96)=21.78$, $p<.01$, $\eta^2=.80$. Sixth graders outperformed fifth graders on the word problem test. There was also an interaction between grade and group, $F(1, 96)=3.97$, $p<.05$, $\eta^2=.15$. There was no difference between two groups in sixth graders. However, students in the self-explanation group outperformed those in the control group in the fifth graders.

3.3. Results of the Transfer Test

The transfer test consisted of 18 problems. The score given to the problem was one point, when students generated a correct description. So, the maximum score of the transfer test was 18 points. The results of the transfer test are presented in the right column of Table 1. As a result of the 2(grade) x 2(group) ANOVA, there were neither main effects nor an interaction between grade and group.

Table 1

Mean Scores (Ms) and Standard Deviations (SDs) for Each Group as a Function of Test Type

Group	Word Problem Test M	Word Problem Test SD	Transfer Test M	Transfer Test SD
		Fifth Graders		
SE (n=24)	10.04	4.33	9.79	4.21
Control (n=28)	7.68	3.86	9.64	3.81
		Sixth Graders		
SE (n=23)	12.04	3.66	9.73	3.67
Control (n=25)	12.64	3.15	8.24	4.54

Note.n=number of students. SE=self-explanation.

3.4. The Relation Between Performance Data and the Explanation Data

After students in the self-explanation group gave a response of "yes" or "no" to a problem solution at each step of the worked-out example, they explained each solution step. We compiled to a total number of 26 solution steps of four kinds of worked-out examples to analyze the verbal protocols of the students in the self-explanation group.

The analysis of their verbal protocols led us to define four kinds of self-explanation: no response, repetition, monitoring, and inferential explanation. When students gave no responses, we classified the explanation data as they did not understand the steps. Self-explanation by repetition means that students repeat or paraphrase the sentential expression that is described in the problem sentences. Self-explanation by monitoring has two characteristics. One type of monitoring means that students understand what the sentential expression means but he or she does not know how to self-explain the content of it. The other type of monitoring means that students do not understand what the sentential expression means. Self-explanation by inference means that students generate new pieces of knowledge not explicitly stated in each step that are related to the problem solution. For example, a student self-explained a solution step ("Two thousands and one hundred yen mean the cost of seven children") of the difficult word problem as follows: The cost of one adult equals that of two children. Two adults deserve to be four children. So, the cost of two adults and three children means that of seven children. We generally refer to inferential explanation as such more fine-grained self-explanation.

We classified students into two groups according to the number of inferential explanations. We chose 8 fifth graders and 11 sixth graders who generated more than .four inferential explanations at the 26 solution steps. They were called high self-explainers. We also classified the remaining 16 fifth graders and 12 sixth graders who generated less than four inferential explanations. They were called low self-explainers.

Two graduate students independently classified the sentential expressions of 26 solution steps for each participant. The proportion of their agreement was .91 for four kinds of self-explanation. Fifth graders of high explainers generated 4.3 inferential explanations and sixth graders of high explainers generated 7.2

inferential expressions. In contrast, fifth graders of low self- explainers generated only 1.7 self-explanations by inference and sixth graders of low self-explainers generated 2.5 inferential expressions.

The results of mean scores of the word problem test for high self-explainers and low self-explainers are presented in the left column of Table 2. A 2(grade) x 2(group) ANOVA showed that there was a significant main effect of group ($F(1,43)=19.47$, $p<.01$, $\eta^2=.83$).

The results of mean scores of the transfer test for high self-explainers and low self-explainers are presented in the right column of Table 2. The results of a 2 x 2 ANOVA showed that there was a significant main effect of group ($F(1,43)=9.62$, $p<.01$, $\eta^2=.73$).

Overall, the results showed that high self-explainers of both fifth and sixth graders outperformed low self-explainers of them on both word problem and transfer tests.

Table 2

Mean Scores (Ms) and Standard Deviations (SDs) for High Self-Explainers and Low Self-Explainers as a Function of Test Type

Group	Word Problem Test M	Word Problem Test SD	Transfer Test M	Transfer Test SD
	Fifth Graders			
High SEers (n=8)	13.75	1.91	13.25	2.05
Low SEers (n=16)	8.19	3.85	8.06	3.75
	Sixth Graders			
High SEers (n=11)	13.67	3.11	10.45	4.06
Low SEers (n=12)	10.54	3.48	8.85	3.29

Note.n=number of students. SEers=self-explainers

4. DISCUSSION

The results of the present experiment are summarized as follows: (1) There was a significant interaction between grade and group on word problem tests. Namely, there was no difference between the self-explanation group and the control group of sixth graders, but students in the self-explanation group outperformed those in the control group of fifth graders. (2) High self-explainers of both fifth and sixth graders outperformed low self-explainers on both word problem and transfer tests.

It is well known that self-explaining worked-out examples has proved effective in improving performance in a variety of domains (Atkinson, Derry, Renkl, & Wortham, 2000). When fifth-grade students first respond to the solution steps of each worked-out example with yes or no and then self-explain them, self-explaining worked-out examples are effective with respect to solving word problems having similar structure to worked-out examples. However, sixth graders in the self- explanation group of the present experiment did not appear to benefit from self-explaining worked-out examples, although Tajika et al. (2007) used sixth graders as participants and they showed the self-explanation effect.

The reason why a similar facilitative effect has not been obtained in the present experiment using sixth graders seems to be that word problems including elimination and decimals are easy to solve. Tajika et al. (2007) used ratio word problems. When we compare the scores of ratio word problems for the control group of Tajika et al. (2007) with those of word problems including elimination and decimals for the control group in this experiment, we find that scores on the ratio word problems are much lower than those on the word problems including elimination and decimals. The first results suggest that self- explaining worked-out examples is an effective metacognitive strategy for fifth graders, but is not effective for sixth graders solving easy word problems.

It is also difficult to explain the results of the transfer test. The one possible explanation is that self-explanation effects have not been transferred to the other test because of the use of easy word problems.

The results involving high self-explainers and low self-explainers supported the hypothesis that high self-explainers who generate more self-explanations relating to deep understanding of word problems would outperform low self-explainers on word problem and transfer tests. High self-explainers generated more fine-grained self-explanation inferences at each solution step on word problems. For example, a student self- explained a solution step for a difficult worked-out example as follows: The cost of one adult equals that of two children. Two adults deserve to be four children. So, the cost of two adults and three children means that of seven children.

As stated earlier, we have pointed out that monitoring usually refers to both comprehension and a comprehension failure. Even high self-explainers sometimes self-explain solution steps as a comprehension failure type of monitoring. However, monitoring activities by high self-explainers were different from those by low self-explainers. High self-explainers tried to find the flaw in their knowledge that caused the comprehension failure and tended to monitor the comprehension failure more clearly. Even if some students gave yes responses to solution steps in the worked-out examples, they only repeated sentences of solution steps, instead of explaining solution steps to themselves. Eleven high self-explainers of the sixth graders and eight high self-explainers of the fifth graders generated more self-explanations and more fine-grained explanations. Students self-explained solution steps for word problems to actively integrate prior knowledge with information contained in solution steps. Findings indicate that while high self-explainers used self- explanations as a metacognitive strategy to make incomplete understanding complete, low self-explainers did not learn much from solution steps in the worked-out examples during self-explaining. Judging from the results of the high self-explainers, it may be suggested that self-explanation is an effective metacognitive strategy when dealing with not only mathematical word problems but also transfer problems. When metacognitive strategies such as self-explanations are effectively used to learn from worked-out examples, students may improve mathematical solution skills by reconstructing incomplete mental models they have.

5. CONCLUSIONS

Research on self-explanations suggests that generating self-explanations is useful in general. Chi (2000) also points out that generating incorrect self- explanations does not depress effective performance. When they first gave yes or no responses to the questions about whether they understood a problem solution at each step and then self-explained each worked-out example in the present experiments, we attempted to make students self-explain more. Self- explaining may have encouraged students to integrate information presented in word problems with their prior logico-mathematical knowledge.

The most commonly used technique in mathematics textbooks for helping students solve word problems is to provide worked-out examples. Worked-out examples typically present solutions in a step-by-step fashion. Worked-out examples have three steps. They consist of a problem formulation, solution steps, and the final solution (answer). We found that worked-out examples became a more effective technique when even elementary school children self-explained each solution step of worked-out examples.

Although research on mathematical problem solving by self-explaining worked-out examples has found facilitative effects using this instructional approach, two main factors influencing performance can be stated on the basis of the above results using fifth and sixth graders (see Renkl, 2005). (1) The importance of providing elaborated solution steps in worked-out examples. Few elementary school children generate inferences to explain each solution step in worked-out examples. Many of them only reread each solution step or repeat statements. We should ask students to self-explain each solution step in worked-out examples. As a result, we should provide elaborate solution steps in worked-out examples which students easily generate inferences to explain. (2) Traditional worked-out examples show just one type of solution step procedure. However, elementary school teachers often provide students multiple solution procedures dependent on mathematical problem types. We need to provide several types of solution step procedures in a worked-out example.

6. ACKNOWLEDGEMENTS

This study was supported by a Grant-in-Aid for Scientific Research (C) 20530613, from the Japan Society for Promotion of Science. The authors extend their sincere thanks to the students who participated in the study, their teachers, and a school principal.

7. NOTES

The results from this study were presented at the 51th Annual Meeting of the Japanese Association of Education Psychology, September 2009. The paper of this study was also published in Japanese with the journal "Graduate School Bulletin of the Kobe Shinwa Women's University, 2010, 6, 113-120". The data of the paper were the same but many sections of it were changed. Students in the control group were also given worked-out examples after the experiment and were informed that self-explanations would help them to solve word problems and transfer problems.

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