愛知教育大学教育実践総合センター紀要
第9号, pp. 9～16 (February, 2006)

The Effect of Self-Explanation on Solving Mathematical Word Problems

(2005年10月12日受理)

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Abstract

The purpose of the study was to examine how a metacognitive strategy known as self-explanation influences word problem solving in elementary school children. Participants were 73 sixth-graders. They were assigned to one of three groups, the self-explanation group, the self-learning group, or the control group. Students in each group took two kinds of tests. The results showed that students in the self-explanation group and students in the self-learning group outperformed students in control groups on a transfer test. In addition, high explainers who generated more self-explanations relating to deep understanding of ratio word problems outperformed low explainers on ratio word problem andtransfer tests. The self-explanation effect is discussed.

Key Words:metacognitive strategies, self-explanations, mathematical problem solving, worked-out examples

1. Introduction

Many researchers have focused on metacognitive strategies that facilitate knowledge construction as a way to get students to learn with greater understanding (Flavell, 1979; Palincsar & Brown, 1984; Schoenfeld, 1987). It is well known that there are a variety of metacognitive strategies, for example, self-questioning, asking questions, answering questions, summarizing, notetaking, and drawing. Self-explanations are often used as one of the metacognitive strategies. We focus on a particular metacognitive strategy, self-explanation.

Recent research has shown that self-explanation is an effective metacognitive strategy across a wide range of 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, 2005). A number of studies have shown that students generally learn 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 explain their own problem-solving steps (Berardi-Coletta, Buyer, Dominowsky, & Rellinger, 1995; Neuman & Schwarz, 1998, 2000; Tajika & Nakatsu, 2005).

Self-explanations are the activity of explaining to oneself in an attempt to understand new information presented in a text. Chi (2000) distinguishes self-explanation from self-explaining and defines the term self-explanation as referring a unit of utterances generated by self-explaining. However, self-explanations are referred to as self-explaining in this study. The activity of explaining to oneself is distinct from other metacognitive strategies such as self-questioning, asking questions, and answering questions. For example, the activity of self-questioning can help students. When students must generate inferences beyond information given, self-explanations may be one of the most effective metacognitive strategies (e.g., Chi et al., 1989).

Chi et al. (1989) analyzed the self-explanations which university students generated while studying worked-out examples and solving mechanics problems. They divided students into successful students and unsuccessful students based on problem solving performance. They showed that the successful and unsuccessful students differed with respect to both quantitative and qualitative aspects of self-explanations. The successful students 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 the successful students learned with understanding. Chi et al. (1994) also found that the greater the number of self-explanations generated by eighth-graders, the better they learned an expository text.

Research on self-explanations has also 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 & Nakatsu, 2005). For example, Nathan et al. (1994) examined how the self-explanation process related to learning and subsequent problem-solving performance. They manipulated the problem-solving tasks (algebra manipulation tasks versus algebra story problem translation tasks) and cognitive load (a high load versus a low load). University students had to generate their own solution to an algebra problem in the high load task. They had to study a worked-out example solution to the same algebra problem in the low load task. The results of their study showed that self-explanations 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.

Neuman and Schwarz (2000) also examined the role of self-explanation in solving algebra word problems. They asked ninth-grade students to solve three mixture word problems while the students thought aloud. They analyzed the protocols of the students' solution processes. The results showed that the role of self-explanations during solving problems not only uncovered the deep structure of problem representation, but also mediated the artifact representations such as tabular representations.

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. The results showed that 10th-grade students who explained their solution steps during problem-solving practice with computer-based environments learned with greater understanding compared to students who did not explain their solution steps.

It is well known that young school children do not use a variety of metacognitive strategies because they do not know much about their problem-solving processes (Brown, 1997). Furthermore, they do not know about monitoring their own activities. However, Flavell, Green, and Flavell (1995) have reported that by age 7 or 8, elementary school children improve at appreciating the value of cognitive strategies. If school children employ metacognitive strategies, facilitative effects due to self-explanations will be found in sixth grade students when they are asked to solve word problems while self-explaining the solution steps.

Tajika and Nakatsu (2005) used ratio word problems to examine the effects of self-explanations used by elementary school children. They conducted an experiment in which sixth-graders were divided into three groups (self-explanation, self-learning, and control). Students in the self-explanation group and students in the self-learning group received two kinds of ratio word problems as worked-out examples and were trained with these worked-out examples. Students in the self-explanation group were instructed to self-explain each solution step of the worked-out examples. Students in the self-learning group were instructed to understand each of the same solution steps of the same worked-out examples. The results showed that 6th graders in the self-explanation group outperformed both students in the self-learning group and the control group on the transfer test. The results also showed that there was no difference in the ratio word problem test among three groups.

Why was there no difference in the ratio word problem test among the three groups in our study (Tajika & Nakatsu, 2005)? The present study was designed to extend the results of Tajika & Nakatsu (2005) using a modified procedure. In Tajika & Nakatsu (2005), students in the self-explanation group wrote their explanations in pencil while studying worked-out examples. Some students had troubles in writing down their explanations. As a result, it seemed that there was no difference in performance on the ratio word problem test among the three groups. In the present study, students in the self-explanation group had an interview about their explanations. They were asked to self-explain each step of worked-out examples to the experimenters. The experimenters wrote down the participants' explanations. As a result, students in the self-explanation group found it easier to explain more frequently at each step. By using the interview procedure, we may more accurately assess how a metacognitive strategy known as self-explanations influences word problem solving in elementary school children.

Research on learning from worked-out examples has shown that whole some students generate more self-explanations relating to deep understanding of texts and/or mathematical problems, other students do not (e.g., Chi et al., 1989, 1994; Renkl, 1997). Students who generate more self-explanations relating to deep understanding of mathematical problems outperform students who generated fewer self-explanations on mathematical problems. We call students high explainers, who generate more self-explanations relating to deep understanding of mathematical problems. We also call the students low explainers, who generate less self-explanations relating to deep understanding of mathematical problems.

We hypothesized that students in the self-explanation group would outperform students in the other two groups on ratio word problem and transfer tests. We also hypothesized that high explainers generating more self-explanations relating to deep understanding would outperform low explainers on both ratio word problem solving and transfer tests.

2. Method

2.1. Participants

The participants were 73 sixth-grade children (mean age was 11 years 7 months) in an elementary school in Japan. They were assigned to one of three groups; the self-explanation group, the self-learning group, or the control group. The self-explanation group had twenty-five students (thirteen girls and twelve boys). The self-learning group (twelve girls and twelve boys) and the control group (eleven girls and thirteen boys) had twenty-four students, respectively.

2.2 Materials

2.2.1 The tests used in the experiment

A total of three kinds of test were used in the present experiment; a pretest, a ratio word problem test, and a transfer test.

The pretest consisted of 4 ratio word problems used in a previous study by Tajika, Nakatsu, and Nozaki (2001). It was used to examine students' performance of ratio word problems. The ratio word problem test consisted of 8 problems, four easy problems and four difficult problems. The test was also used in the study by Tajika and Nakatsu (2005).

The transfer test consisted of an 18-item word problem test, adapted from a multiple-choice test used by Mayer, Tajika, and Stanley (1991). The test was also used in the study by Tajika and Nakatsu (2005). It had three kinds of question. One kind of question was to make a number sentence from such a sentence 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.?"

All materials were presented in Japanese.

2.2.2. Worked-out examples used in the experiment

Two kinds of worked-out examples were also used in the experiment. The worked-out examples contained two kinds of ratio word problem, an easy word problem and a difficult word problem. The easy worked-out example problem which students in the self-explanation group and the self-learning group received consisted of five solution steps. The difficult worked-out example problem which students in the self-explanation group and the self-learning group also received consisted of seven solution steps. The worked-out examples were the same numbers of steps as those used by Tajika and Nakatsu (2005). Students in the self-explanation group were asked to self-explain each solution step. The experimenter wrote down the students' explanations in the blank spaces on the example sheet during self-explaining for each solution step. The easy and difficult worked-out example problems which students in the control group received consisted of the same problems as those in the self-explanation and self-learning groups. They contained problem sentences of both easy and difficult problems, each numerical expression as a solution step, and their answers.

The easy worked-out example problem was as follows: "The science club has a capacity of 30 students at the elementary school. The ratio of students who hope to become members of the science club is 0.6. What is the number of students who hope to become members of the science club at the school?"

The easy worked-out example problem had five solution steps and the answer in the self-explanation and self-learning groups. (Step 1) The science club has a capacity of 30 students. (Step 2) The science club has a capacity of 30 students, and it is called the basic quantity. The ratio of the basic quantity is 1. (Step 3) The number of students who hope to become members of the science club is unknown. However, the ratio of the students who hope to become members is 0.6 when the ratio of the capacity of the science club is 1. (Step 4) The ratio of the students who hope to become members of the science club is expressed with the diagram (see Fig. 1). (Step 5) As the diagram

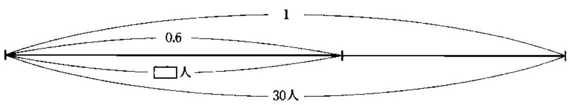

Fig. 1. The diagram of the easy worked-out example

expresses the ratio of the capacity of the science club consisting of 30 students as 1, the ratio of 0.6 is 30 x 0.6 = 18. (Answer) The answer is 18 (30 x 0.6 = 18).

The difficult worked-out example problem was as follows: "When the tank is filled up with water, it takes 10 minutes for the A faucet to fill up the tank and it takes 15 minutes for the B faucet to fill up the tank. When both A and B faucets are turned on at the same time, how long does it take to fill up the tank with water?"

The difficult worked-out example problem had seven solution steps and the answer in the self-explanation and self-learning groups. (Step 1) When only the A faucet is turned on for one minute, the ratio with which the tank is filled up with water is 1/10. (Step 2) When only the B faucet is turned on for one minute, the ratio with which the tank is filled up with water is 1/15. (Step 3) When both A and B faucets are simultaneously turned on for one minute, the ratio with which the tank is filled up with water is (1/10 +1/15). (Step 4) When the ratio of the water with which the tank is filled up for one minute is described with the diagram, the diagram is as follows (see Fig. 2). (Step 5) When both A and B faucets are simultaneously turned

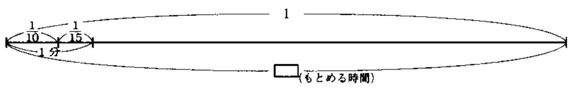

Fig. 2. The diagram of the difficult worked-out example

on for one minute, the ratio with which the tank is filled up with water is 1/6 (1/10 + 1/15 = 5/30 = 1/6). (Step 6) The diagram shows that the ratio with which the tank is filled up with water is 1. (Step 7) When the ratio with which the tank is filled up with water using both faucets for one minute is 1/6, it takes 6 minutes (1 /1/6) to be filled up with water. (Answer) The answer is 6 (1 /(1/10 +1/15)) = 6).

2.3. Procedure

The experiment had four sessions and was carried out individually. First, students took a pretest which took 20 minutes and consisted of 4 ratio word problems. Second, one week after the pretest, students in the self-explanation group and the self-learning group studied two worked-out examples. Students in the control group studied the same two problems as those in the self-explanation group and the self-learning group. The problems which students in the control group studied contained only numerical expressions and the answers. Students in the self-explanation group had an interview about their explanations. They were instructed to self-explain the problem solution at each step. The experimenter wrote down participants' explanations. Students in the self-explanation group did not receive feedback on their explanations. Students in the self-learning group were instructed to understand a problem solution at each step. Students in the control group were given the numerical expressions and the answers for the problems. The teacher explained the easy and difficult problems including numeral expressions and the answers and then instructed students to understand how to solve each problem. Each group was given 20 minutes to work on each of the above activities.

Third, after studying the worked-out examples in each group, students in each group took a ratio word problem test that consisted of 8 problems with a time limit of 40 minutes. The test contained four easy problems and four difficult problems. Fourth, one month after the ratio word problem test, each student took an 18-item transfer test. It took 30 minutes.

3. Results

3.1. Results of the pretest

The pretest consisted of four problems. The score of each problem was 2 so that the maximum score of the pretest was 8. The mean score and the standard deviation (*SD*) in each group were as follows. The mean score of the self-explanation group was 4.00 ($SD=1.70$). The mean score of the self-learning group was 4.17 ($SD=1.28$). The mean score of the control group was 4.13 ($SD=1.68$). There was no difference among three groups, $F(2,70)<1$.

3.2. Results of the ratio word problem test

The ratio word problem test consisted of eight problems. The score of each problem was 2, so the maximum score of the ratio word problem test was 16. The results of the ratio word problem test are presented in Table 1. As shown in Table 1, the mean score of the self-explanation group was 8.80 ($SD=2.53$). The mean score of the self-learning group was 7.96 ($SD=3.63$). The mean score of the control group was 8.58 ($SD=3.00$). There was no difference among three groups, $F(2,70)<1$.

3.3. Results of the transfer test

The transfer test consisted of 18 problems. The score of each problem was 1, so the maximum score of the transfer test was 18. The results of the transfer test are also presented in Table 1. As shown in Table 1, the mean score of the self-explanation group was 15.04 ($SD=1.93$). The mean score of the self-learning group was 12.92 ($SD=2.45$). The mean score of the control group was 13.33 ($SD=2.68$). There was a significant difference of performance among three groups, $F(2,70)=5.56$, $p<.01$. Post-hoc HSD tests (p-values <.05) revealed that the self-explanation group showed higher performance than both self-learning group and control groups.

Table 1

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

Group	Ratio Word Problem Test		Transfer Test	
	M	SD	M	SD
Self-Explanation (n=25)	8.80	2.53	15.04	1.93
Self-Learning (n=24)	7.96	3.63	12.92	2.45
Control (n=24)	8.58	3.00	13.33	2.68

3.4. Results of the intercorrelations between test scores

The intercorrelations between test scores were analyzed on the basis of the data from all students. The correlation between pretest and ratio word problem test scores was .66 ($p<.01$). The correlation between pretest and transfer test scores was .12 (p=ns). The correlation between ratio word problem test and transfer test scores was .20 (p=ns).

3.5. The relation between performance data and the explanation data

Students in the self-explanation group explained solution steps in each worked-out example and then solved the ratio word problems. Some students explained solution steps in each worked-out example much more extensively than other students. We chose eleven students who generated more explanations and more fine-grained explanations. They were called high explainers. We also chose the remaining fourteen students who generated fewer explanations and/or only repeated the sentences of solution steps. We call them low explainers. We analyzed the data of these two groups.

The mean scores of the pretest were 4.91 ($SD=1.72$) in the group of high explainers and 3.69 ($SD=1.28$) in the group of low explainers, respectively. The two groups did not differ concerning the pretest scores ($t(23)=1.83$, ns).

The results of each test are presented in Table 2. The mean correct score of the ratio word problems in the group of high explainers was 10.36 ($SD=2.22$). The mean correct score of the ratio word problems in the group of low explainers was 7.57 ($SD=2.02$). The difference was also significant between these two groups, $t(23)=3.32$, $p<.01$.

Table 2

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

Group	Ratio Word Problem Test		Transfer Test	
	M	SD	M	SD
High Explainers (n=11)	10.36	2.22	16.00	1.41
Low Explainers (n=14)	7.57	2.02	14.28	1.86

The mean correct score on the transfer test in the group of high explainers was 16.00 ($SD=1.41$). The mean correct solution on the transfer test in the group of low explainers were 14.28 (*SD*=1.86). The difference was also significant between the two groups, $t(23)=2.23$, $p<.05$.

The analysis of the verbal protocols of the students in the self-explanation group led us to define three kinds of self-explanation: repetition, monitoring, and inferential explanation. Self-explanation by repetition means that students repeat the sentential expression which is described in the problem sentences. Many low explainers and some high explainers generated self-explanations by repeating sentences that were described in solution steps. Monitoring usually refers to both comprehension and a comprehension failure, which has been found in both high and low explainers. An inferential explanation means that students infer a new sentential expression on the basis of the existing sentences of each solution step. High explainers generated self-explanations of such inferential ones more often than low explainers.

4. Discussion

The results of the present study were similar to those of Tajika and Nakatsu (2005). The present results are summarized as follows. (1) Students in the self-explanation group outperformed students in the self-learning group and students in the control group on the scores on the transfer test. However, there was no difference among three groups on the scores for solving the ratio word problems. (2) High explainers who generated more self-explanations relating to deep understanding of ratio word problems outperformed low explainers on both ratio word problem and transfer tests.

The only difference of the results between the present study and that of Tajika and Nakatsu (2005) was found on the transfer test. In Tajika and Nakatsu (2005), there was no difference on the transfer test scores between students in the self-explanation group and students in the self-learning group. However, the present result of the transfer test supported the hypothesis that students in the self-explanation group would outperform students in the other two groups.

The interview procedure used in the present study was different from the procedure used by Tajika and Nakatsu (2005). In the interview procedure each student had to tell an experimenter what they had thought at each solution step. Even though some of their inferences were wrong, students generated more inferences compared to students in Tajika and Nakatsu (2005) where they were asked to write down their inferences. Inferences can be generated by integrating information presented in ratio word problems with prior logico-mathematical knowledge. They may have helped students in the self-explanation group to outperform those in the self-learning group.

There was also no difference among the three groups on the ratio word problem test. The result replicated that of Tajika and Nakatsu (2005). One possible explanation is about the procedure of our study. Renkl, Stark, Gruber, and Mandl (1998) measured the learning results from self-explanations with two types of transfer tests, a near-transfer test and a far-transfer test. They found that self-explanations fostered both types of transfer. In their experiment, students in the experimental group were presented a model depicting how to self-explain a worked-out example and received self-explanation training, whereas students in the control group only received training in how to think about a worked-out example. As a result of their experimental manipulations, Renkl et al. (1998) found self-explanations to be effective.

In our experiment, on the other hand, we did not train students how to self-explain the solution steps of each worked-out examples. Instead, we just made students self-explain the worked-out examples. Moreover, we did not provide students with feedback on self-explanations, so that they did not know whether their self-explanations were correct or incorrect.

It is well known that the use of worked-out examples has proved effective in a variety of domains (Atkinson, Derry, Renkl, & Wortham, 2000). However, the results of our study suggest that when students are not trained how to self-explain or self-learn the solution steps of each worked-out example, then the use of worked-out examples are not effective with respect to solving word problems having similar structure to worked-out examples.

We can see individual differences with respect to the number and quality of self-explanations. As Renkl (2002) has pointed out, learning from self-explanations has some restrictions, even when effective self-explanations are trained or elicited. Renkl (2002) found that the quality and correctness of self-explanations were far from being optimal and that some students had substantial comprehension problems, irrespective of whether they were supported by the elicitation procedure or not. Our study is also consistent with the self-explanations' point of view of Renkl (2002). As a result, students in the self-explanation group and students in the other two groups did not differ in respect to the scores of the ratio word problem test.

The second result supported the hypothesis that high explainers who generate more self-explanations relating to deep understanding of ratio word problems would outperform low explainers on both ratio word problem and transfer tests. The result replicated that of Tajika and Nakatsu (2005).

Every student was not facilitated in solving ratio word problems by self-explaining the solution steps in each worked-out example. Some students generated more self-explanations and better self-explanations relating to deep understanding than other students did. Eleven of them were classified as high explainers. We classified students as high explainers, who generated more than 70 % monitoring and inferential explanations at both worked-out examples. They generated inferential explanations which inferred new sentential expressions on the basis of the existing sentences of each solution step. They generated a number of inferential explanations. For example, one high explainer's explanation of the first solution step of the difficult worked-out example was th at, "It takes 10 minutes for only the A faucet to fill up the tank with full water. So, the ratio of the A faucet is 1/10 for one minute."

In contrast, many students repeated sentences of solution steps in the worked-out examples. A few students did not explain solution steps to themselves at all. Fourteen of them were classified as low explainers. Low explainers sometimes said that they did not understand what the sentences meant. Low explainers often monitored the solution steps in which they failed to understand the meaning of the sentences. One low explainer said that she did not understand why the diagram was described in such a way.

As stated earlier, we pointed out that monitoring usually refers to both comprehension and a comprehension failure. Even high explainers sometimes generated self-explanations as a comprehension failure type of monitoring. However, monitoring activities by high explainers were different from those by low explainers. High explainers tried to find the flaw in their knowledge that caused the comprehension failure and tended to monitor the comprehension failure more clearly.

As stated above, many students only repeated sentences of solution steps in the worked-out examples, instead of explaining solution steps to themselves. Eleven high explainers generated more self-explanations and more fine-grained explanations relating to deep understanding of ratio word problems than fourteen low explainers. Students are devoted to self-explaining solution steps of ratio word problems to actively integrate prior knowledge with information contained in solution steps. Findings indicate that while high explainers used self-explanations as a metacognitive strategy to make incomplete understanding complete, low explainers did not learn from solution steps in the worked-out examples during self-explaining.

Judging from the results of high 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 trained effectively while learning from worked-out examples, students may improve mathematical solution skills by reconstructing incomplete mental models they have.

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Acknowledgements

This study was supported by a Grant-in-Aid for Scientific Research (B), No. 15330141, from the Japan Society for Promotion of Science. The study was presented at the 11th Biennial Conference of the European Association for Research on Learning and Instruction, Nicosia, Cyprus, August 2005. The authors would like to express their appreciation to Professor Ewald Neumann, University of Canterbury, Christchurch, New Zealand, for his helpful comments on an earlier draft. The authors would also extend their sincere thanks to the students who participated in this study, and to their teachers and a school principal. After the final test period, students in the self-learning group and the control group were informed that self-explanations would help them to solve both ratio word and transfer problems.