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The Effects of Metacognitive Instruction on Higher and Lower Achiever in Solving Mathematical Word Problems

Afia Iqbal*, Naveed Sultana** & Muhammad Tanveer Afzal***

Abstract

Present study examined the differential effects of metacognitive instruction, called SAVE the TIME, on Students of elementary level in solving mathematical word problems. In particular, the study focused on the higher and lower achievers of sixth grade. Participants were 160 students of sixth grade of district Abbottabad who studied in male (N = 80) and female (N = 80) public schools. All students were administered pretest and posttest constructed of 10 mathematical word Problems. Student of each gender were randomly divided in two groups experimental and control. Students in each group were also assigned into higher and lower achiever group on the basis of pretest scores and consultation with their teachers. Experimental groups of each gender were exposed to metacognitive instruction strategy SAVE the TIME and control group was taught by traditional method. The findings indicate that students exposed to SAVE the TIME of both gender significantly outperformed their counterparts in the control group, higher achiever and lower achiever both groups benefited from SAVE the TIME. In addition, the study indicates that there was not any difference in achievement between male and female higher achievers and male and female lower achievers exposed to SAVE the TIME.

Keywords: Metacognitive instruction, mathematical word problems, traditional method, self-addressed questions

*PhD Scholar, Department of Secondary Teacher Education, AIOU Islamabad
**Associate Professor, Department of Secondary Teacher Education, AIOU Islamabad
***Assistant Professor, Department of Secondary Teacher Education, AIOU Islamabad

Introduction

Mathematics is a compulsory subject of the curriculum at elementary and secondary level throughout the world. An important component of mathematics syllabus is mathematical word problems which are considered as the most difficult topic by majority of the students. Usually students have horrible reminiscences related to mathematical word problems. They hesitate to solve mathematical word problem and prefer to solve other questions in paper as well. Researchers have used various Instructional strategies for solving word problems. A good Instruction strategy for teaching mathematics makes students able to solve not only the word problems given in exercise but the problems faced in daily life as well. At present teachers and researchers know more about the difficulties that students face in solving mathematical word problems, but less about how to deal with such difficulties. Generally students are indirectly trained to memorize the word problems or look for the keywords or hints given in word problem instead of trying to comprehend the problem and using previous knowledge to solve it (Verschaffel et al. 2000). A profound understanding is necessary to solve a word problem. Different techniques have been suggested by educationists to deal with the difficulties students face in solving word problems (Swee-Fong & Lee, 2009). Many researchers have established a positive relationship between metacognitive instruction and student's achievement (Maqsud, 1997; Helms-Lorenz & Jacobse, 2008). Valerie et al. (2010), found that metacognitive instruction had a noticeable effect in the use of metacognitive skills to solve mathematical word problems and enabled the low achievers to make progress. Fazal et al, (2010), and Jaleel & Chandran (2016), did not find any significant difference between metacognitive awareness of male and female science students. Zheng (2005), showed that male students performed well as compared to female students in mathematics while Anandaraj & Ramesh (2014), proved that Female physics major students are better than male students in their metacognition.

On the basis of these findings, in the present study, researcher attempted to find the effect of metacognitive instruction, compare the achievements scores of higher and lower achiever and also compare the achievements of higher and lower achiever across gender in mathematical word problems.

Metacognition

Metacognition, a term introduced by John Flavell of Stanford University in 1976, refers to the thinking about one's own thinking, one's own knowledge and concern of cognitive processes and strategies. Metacognition is the basic skill that makes learning effective. Taylor (1987) defines metacognition as "an appreciation of what one already knows, combined with a correct apprehension of the learning task, with knowledge and skills it requires, together with the capability to make accurate inferences about how to apply one's strategic knowledge to a particular situation, and to do so proficiently and reliably."

Metacognition is like an inner guide that detects when your understanding and reminiscence works, when your attention diminishes, when your thinking is right or wrong, if you have not learned something, and so on. This inner guide will take action if it is to relocate attention, rereading, considering the thought, taking some mental moves or asking questions to deal with the condition competently. There are three associated elements of metacognition in the field of learning and instruction, particularly solving mathematical word problems (Lester, 1994).

1. Metacognitive knowledge: knowledge about one's own cognition or thinking process (e.g. what does one know about his own thinking?)
2. Metacognitive beliefs: beliefs and perceptions (e.g. what thoughts one carries during work in mathematics and how they help in solving mathematical word problems?).
3. Executive control: monitoring of activities during problem solving (e.g. how well does one reveal and use it in solving a problem?

Metacognitive skills are concerned with the procedural knowledge of a problem, and permit students to organize their learning activities (Verschaffel et al., 1999). Metacognitive skills help students to observe the problem or task cautiously, to develop a plan, and to reflect upon and evaluate the solutions obtained (Zimmerman, 2008). Three metacognitive skills that were used most regularly during the solution of word problems are self-instruction, self-questioning and self-monitoring (Montague, 1992). Use of metacognitive strategies by students make them more confident, competent and independent learners. Metacognitive skills of students can be stimulated by asking effective questions during problem solving (Hacker and Dunlosky, 2003). Teachers' questions such as 'What about next?', 'What do you think?', 'Why do you think so?' and 'How can you attest this?' can develop the metacognitive abilities of students (Yurdakul, 2004).

Metacognitive instruction and mathematical word problems

Generally students hesitate to solve mathematical word problems because they fail to, understand and analyze the problem, organize the necessary mathematical procedures, decide on the correct strategy, and monitor and evaluate the operations performed (Victor, 2004). With the help of the structured activities metacognitive strategy instruction offers students about the knowledge of the cognitive strategies and processes, understanding and practice in the use of the cognitive and metacognitive strategy and the evaluation of the results of their hard work (Goldberg and Bush, 2003).

Students without metacognitive skills fail to monitor their understanding. They simply work through a word problem with little recognition of what made sense and what didn't. Appropriate teaching methods that have the potential to enhance metacognition, the basic skill that makes learning effective; have been developed by researchers in past two decades (Bracha, 2002; Dignath, Buettner, & Langfeldt, 2008). Metacognitive instruction makes students smarter, being able to use their abilities in an improved manner. Students trained by metacognitive instruction become strategic; they try to understand the word problem before solving it, monitor their comprehension as they read the question. in fact, they perceive when they don't pick up something so they do something to comprehend it (e.g., re-read, consider that something doesn't make any logic and decide to come back to it later, stop and reflect , ask questions about it, etc.).

The role of metacognition is significant in all steps of mathematical word problem solving. Researchers have confirmed that just the knowledge of what to do during problem solving operations is not sufficient, but the knowledge of when to apply different strategies is also vital (Dinath, 2008). Different studies on metacognition have recognized a strong correlation between metacognition and problem solving ability of student. Similarly the achievement rate of students with higher level of metacognitive skills is high as compared to students with lower level of metacognitive skills in problem solving (Kramarski & Mevarech, 1999).

Van der Stel & Veenman (2008), confirmed a positive relationship between metacognition and students' achievement. Desoete, Royers, & De Clercq (2003), hypothesized that metacognitive training could improve procedural knowledge of students to solve a mathematical word problem and confirmed that the students exposed to metacognitive instruction showed the top scores in post-test of mathematical problems. Valerie et al. (2010), studied the use of metacognitive skills to solve mathematical word problems on low achievers and found a noticeable progress in their results.

A metacognitive instruction strategy SAVE the TIME for solving mathematical word problems was developed by researcher based on the strategies combined by (Montague, 1992; Montague & Dietz, 2009). Its aim is to promote students' metacognitive awareness during word problem solving. SAVE the TIME is an acronym of the word problem solving stages: Study; Analyze; Visualize the word problem; Ensure about the correct visualization, Think about Possible Strategies; Implement those Possible Strategies; Monitor; and Evaluation. At each stage of the word problem solving, there are some questions according to the Say, Ask, and Check component of instructional strategy developed by Montague & Dietz, (2009) to guide the students to control and monitor their procedure and solution. SAVE the TIME was piloted on six students and was found to be an effective strategy to make students become more aware of their thinking process in word problem solving. The effectiveness of metacognitive instruction has been proved through different researches. These researches were restricted to some specific population and areas under consideration therefore researcher conducted present study on metacognitive instruction and achievement in mathematical word problems, effects of metacognitive instruction on higher achiever and lower achiever groups and its differential effects across male and female groups of elementary school students of district Abbottabad.

Objectives and Hypotheses

The present study was designed to examine the effect of metacognitive instruction and student's achievement in mathematical word problems at elementary level. In particular, the study was designed to seek answers to the research question: Is there any significance of applying various teaching techniques on students' learning achievements in mathematical word problems across higher and lower achievers? The objective of the study was translated into following hypotheses.

$H_0 1$: There is no significant difference between achievement scores of students of class six exposed to metacognitive instruction and taught by traditional method.

$H_0 2$: There is no significant difference between achievement scores of higher achievers and lower achievers of class six exposed to metacognitive instruction.

$H_0 3$: There is no significant difference between achievement scores of higher achievers male and higher achievers female of class six exposed to metacognitive instruction.

$H_0 4$: There is no significant difference between achievement scores of lower achievers male and lower achievers female of class six exposed to metacognitive instruction.

Methodology

Participants were 160 Pakistani students who studied in class six in two (male and female) public schools located in district Abbottabad. About half of the participants were female. Participants were randomly selected and randomly divided in experimental and control groups in each school. Among the participants in experimental group, 21 children were diagnosed as higher achievers, and 32 students as lower achievers.

Instruments

To examine the study hypotheses, researcher constructed a test, functioned as both pretest and posttest, consisting of ten mathematical word problems. Test was validated with the help of experts. Alpha Cronbach reliability was found 0.917. Marking rubric was formulated.

Intervention

All students, in both groups, studied mathematics one period daily. Students in experimental group were exposed to a metacognitive instruction SAVE the TIME. While students in control group were taught through traditional method where teacher solves problem on board and students copy it, with no explicit exposure to meta-cognitive instruction. Students in experimental group studied in small groups.

SAVE the TIME was an acronym of the word problem solving stages: Study; Analyze; Visualize the word problem; Ensure; Think about Possible Strategies; Implement those Possible Strategies; Monitor; and Evaluation. At each stage of the word problem solving, there were questions to direct the students to regulate and monitor their solution. In this program, students worked in small, mixed groups constructed of higher, middle and lower achievers. Students worked in small groups to ask and answer metacognitive questions in which students asked each other to express the main problem in simple words, categorize it, select an appropriate strategy to find solution, and recognize similarities and differences with other problems they have solved before.

Procedure

The study followed the treatments of control and experimental groups as per the true experimental pretest- posttest control group design. Students were randomly assigned into control and experimental groups. Pre test was conducted to check the equivalence of the groups before the experiment. Post-test was conducted at the end of the study.

Data Analysis

Data collected was analyzed through applying descriptive statistics and t-test to examine the study hypotheses. The results found are given in the following tables:

Equivalence of Experimental and Control Group

Table 1
Equivalence of Experimental and Control Group on the Scores of Pretest

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Experimental	80	42.137	0.8	18.9220	2.1155	158	0.276	0.782
Control	80	41.337		17.6340	1.715			

*The mean difference is not significant at the .05 level

Results in Table 1 above show that the mean difference (MD = 0.8) of both groups is slightly different. The t- statistics t (158) = 0.276, p = .782, α = .05 provided evidence that both the groups are equivalent and there is no difference between groups before the start of the experiment.

Table 2
Comparison of Mean Scores of Experimental Group in Pretest and Posttest

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Pretest	80	42.137	-10.672	18.922	2.115	158	-3.705	0.000*
posttest	80	52.810		17.483	1.954			

*The mean difference is significant at the .05 level

Results in Table 2 above show that the mean difference (MD = -10.672) for experimental group between pretest and posttest is significantly different (p = .000), and provided evidence that students exposed to Metacognitive instruction achieved enough.

Table 3

Comparison of Mean Scores of Control Group in Pretest and Posttest

	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Pretest	80	41.337	-5.546	17.634	1.971	158	-2.067	0.040*
posttest	80	46.883		16.264	1.818			

*The mean difference is significant at the .05 level

The results given in Table 3 above show that the mean difference (-5.136) of control group between pretest and posttest is significant (p =. 003) and provided evidence that control group students have also shown improvement after teaching by traditional method. The comparison of mean scores in posttest of both groups is presented in the following table.

Table 4

Comparison of Experimental and Control Group on the Scores of Post-Test

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Experimental	80	52.810	6.342	17.483	1.954	158	2.375	.0187*
Control	80	46.468		16.264	1.8184			

*The mean difference is significant at the .05 level

The posttest results in Table 4 above show that the mean difference of two groups (MD = 6.342) is significantly higher (p = .0187). Similarly the mean difference of both groups in pretest and posttest from Table 2 and Table 3 (10.672 - 5.546= 5.126) indicates that achievement scores of experimental group in posttest is higher than that of control group. These results show enough evidence to reject the null hypothesis $H_0$1: There is no considerable difference between achievement scores of students of class six exposed to Metacognitive instruction and taught by traditional method and accept the alternate hypothesis.

Comparison of Achievement Scores of Higher Achiever and Lower Achiever Groups

Table 5

Comparison of Mean Scores of Higher Achiever Groups in Pretest and Posttest

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Pretest	21	65.806	-9.194	7.31	1.59	60	-4.36	0.000*
posttest	21	75.00		6.32	1.37			

*The mean difference is significant at the .05 level

Results in Table 5 above show that the mean difference (MD = -9.194) for higher achiever between pretest and posttest is significantly different (p = .000), and provided evidence that higher achiever students achieved enough when exposed to Metacognitive instruction.

Table 6

Comparison of Mean Scores of Lower Achiever Groups in Pretest and Posttest

	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Pretest	32	32.562	-7.187	7.28	1.287	62	-2.76	0.002*
posttest	32	39.29		7.72	1.38			

*The mean difference is significant at the .05 level

The results given in Table 6 above show that the mean difference (-7.187) of lower achiever Students between pretest and posttest is significantly different (p =. 002) and provided evidence that lower achiever Students have also shown improvement after teaching by metacognitive instruction.

Now we will examine the mean difference of pretest and posttest of both groups to check which group has shown more improvement when exposed to metacognitive instruction.

Table 7

Summary of the Gain Mean Score of Higher and Lower Achievers

Higher Achiever Group	**Lower Achiever Group**
$1P_2 - P_1 1$	**$1\ P_2 - P_1 1$**
9.193	7.187

P_1: pretest mean; P_2: posttest mean;

Summary of the Gain Mean Score from Table7 indicates a significant difference (9.193–7.187= 2.006) between higher and lower Achievers to accept the null hypothesis $H_0 2$: There is no significant difference between achievement scores of higher achievers and lower achievers of class six exposed to metacognitive instruction.

Comparison of Achievement Scores of Higher Achiever Male and Higher Achiever Female Groups

Table 8

Comparison of Higher Achiever Male and Female Groups on the Scores of Posttest

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Male	12	71.81	-0.40	6.27	1.89	19	0.1379	.891
Female	9	72.21		6.68	2.22			

*The mean difference is significant at the .05 level

The posttest results in Table 8 above show that the mean difference (MD = -0.40) of Higher Achiever Male and Female Groups was not significant (p = .891). Similarly the mean difference of both groups in pretest and posttest (9.47 – 8.93 = 0.54) does not indicate any considerable difference. These results show enough evidence to accept the null hypothesis $H_0$3: There is no considerable difference between achievement scores of higher achiever male and female students of class six exposed to Metacognitive instruction, and reject the alternate hypothesis $H_1$1: There is considerable difference between achievement scores of higher achiever male and female students of class six exposed to Metacognitive instruction.

Comparison of Achievement Scores of Lower Achiever Male and Lower Achiever Female Groups

Table 9

Comparison of E Lower Achiever Male and Female Groups on the Scores of Post-Test

Instructional Groups	N	Mean	Mean Difference	Std. Deviation	Std. Error	df	t-value	Sig.
Male	15	40.266	-0.972	7.14	1.85	30	0.3539	0.63
Female	17	39.29		8.39	2.03			

*The mean difference is significant at the .05 level

The posttest results in Table 9 above show that the mean difference (MD = -0.972) was not significant (p = .63). Similarly the mean difference of both groups in pretest and posttest (5.41– 4.93= 0. 58) does not indicate any considerable difference. These results show enough evidence to accept the null hypothesis $H_0$1: There is no considerable difference between achievement scores of lower achiever male and female students of class six exposed to Metacognitive instruction. and reject the alternate hypothesis $H_1$1: There is considerable difference between achievement scores of higher achiever male and female students of class six exposed to Metacognitive instruction.

Discussion

This study shows that experimental group students exposed to metacognitive instruction significantly outperformed the control group on the solution of mathematical word problems.

Similarly higher achiever and lower achiever students in experimental group showed significant improvement than their counterpart in control group. This finding is in line with previous researches. Use of metacognitive skills in the subject of mathematics reveals a positive impact on the performance of learners (Helms-Lorenz & Jacobse, 2008; Van der Stel & Veenman, 2008).

The present study not only confirms the findings of Valerie et al. (2010), that metacognitive instruction enabled the low achievers to make progress but also shows that the higher achiever also benefited from the metacognitive instruction. The present study further shows that higher achiever male and female both benefited from the metacognitive instruction equally and similarly there was no difference in achievement of lower achiever male and female students.

These findings raise a question: why do students exposed to metacognitive instruction benefit more than the students taught by traditional method? As solving mathematical word problems depends on the activation of metacognitive processes, such as planning, implementing sophisticated strategies, monitoring and regulation, and reflection (Montague and Dietz,2009). It is possible that student in experimental group (both higher and lower achievers) used these processes more effectively than students in control group. Mevarech (1999) and Schraw et al., (2006) have indicated that the effective use of strategies require the activation of metacognitive processes.

Since students using metacognitive instruction become more aware about which strategies are appropriate for solving the mathematical word problems and how to apply these strategies, this resulted in a higher level of motivation that positively affected their achievement. Similarly metacognitive instruction affects both male and female groups, to use their previous knowledge to solve new problems, equally.

Conclusions and suggestions for further research

The present study shows that metacognitive instruction for teaching mathematical word problems is not only an effective method for higher achievers but also for lower achievers. It helps students develop the metacognitive learning processes needed to succeed in solving mathematical word problems. It is also proved that the development of metacognition is not a habitual process and metacognitive instruction has positive effects on mathematics achievement. All the stake holders in the educational system should adopt such methods at elementary, secondary as well as in higher secondary levels in country (Mevarech & Fridkin, 2006).

These findings raise quite a few questions for further research, e.g., to what extent can metacognitive instruction improve mathematics achievement of lower achiever? To what extent can metacognitive instruction improve mathematics achievement of early graders? Can the findings reported in this study be generalized to other populations? What are the longitudinal effects of metacognitive instruction? All such issues merit future research.

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