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Effect of Metacognition on Mathematical Reasoning among Secondary School Students

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Abstract- Mathematical reasoning has become an essential tool for all students to cope with the challenges of the modern world. Therefore, the teachers of mathematics should use effective strategies for the developments of mathematical reasoning among their students. The present experimental study focuses on the assessment of the development of mathematical reasoning through metacognition among secondary school students. The major objective of the study was to assess the effect of metacognition on mathematical reasoning in the portion of arithmetic among secondary school students. The nature of this quantitative study was experimental and a pre-test post-test non-equivalent control group was adopted as the research design of the study. Participants of the study were grade 9 students of a government school in Lahore city. There were 34 students in the experimental group and 37 students in the control group. A valid and reliable research instrument was developed for the measurement of mathematical reasoning. A pretest was conducted for participants of the control group and the experimental group. Metacognitive strategies were applied as an intervention for participants of the experimental group. Participants of the control group were taught mathematics without metacognitive strategies. The intervention lasted for the periods of 16 weeks. After the completion of the intervention, a post-test was conducted for the control group and experimental group. An independent samples t-test was applied to compare the mean scores of the control group and experimental group. A significant difference was found between the mean scores of the control group and the experimental group. Participants of the experimental group got more score than participants of the control group. It was concluded that metacognition has a positive effect on the development of mathematical reasoning among secondary school students.
Keywords: Mathematical Reasoning, Arithmetic, Metacognition, Critical Thinking, Secondary School Students

I. Introduction

In mathematics education, metacognition is considered an effective strategy for the teaching and learning of mathematics. It has become a topic of interest in mathematics education research and practices (Ku et al., 2010; Safitri & Arnawa, 2019). Metacognition can be seen as humans' mental ability to monitor and control. In simple words, metacognition is an ability to know about knowing (Dunlosky & Jackoby, 2011). It has been proved that metacognitive teaching and learning strategies have a positive effect on the construction of new knowledge. Metacognitive strategies also support the development of mathematical skills (Kramarski, 2017; Mevarech & Fridkin, 2006; Pirie & kaeran, 1992; Shoenfeld, 2007).

In mathematical skills, mathematical reasoning is considered a higher-order thinking skill. Mathematical reasoning supports the students to apply other mathematical skills in schools and out of schools. Being a critical skill, mathematical reasoning enables students to analyze mathematical situations and logical arguments (Rsmussen & Marrongelle, 2006; Saldana, 2015). Mathematical reasoning also ensures students' better academic achievement in mathematics and other subjects. It enables students to solve problems in daily life activities. The development of mathematical reasoning in all areas of mathematics needs creative teaching and learning strategies (Adams, 2007; Ball & Bass, 2003; Rohana, 2015).

The traditional and teacher-centred teaching strategies are not suitable for the development of mathematical reasoning. In all developed countries, effective teaching and learning strategies are used for the teaching of mathematics. Ineffective teaching strategies, metacognition is considered as a most effective teaching and learning strategy. Developing and underdeveloped countries should also apply metacognitive strategies for the teaching and learning of mathematics. Applications of metacognitive strategies enable students to perform better in mathematics and other subjects (Brodie, 2010; Ponte & Quaresma, 2016; Sidenvall et al., 2015).

In most of the developing and underdeveloped countries, mathematical problems of arithmetic, algebra and geometry are solved with rote memorization. Rote memorization is not suitable for the development of higher-order thinking skills like mathematical reasoning. Therefore, effective teaching and learning strategies should be used to develop mathematical reasoning among the students. Pakistan is also a developing country, which demands skilled students. With the application of metacognitive strategies, Pakistani students can also become skilled force. Therefore, the researcher intended to conduct the study to assess the effect of metacognition on mathematical reasoning among secondary school students. A null hypothesis that there is no significant effect of metacognition on mathematical reasoning among secondary school students was framed. The study focused on one area of mathematics; arithmetic.

II. Literature Review

Mathematics is a useful subject for the prosperity of all individuals, societies, nations and countries. Mathematical content is mainly distributed into three areas: Arithmetic, algebra and geometry (Mustafa, 2011; Sidhu, 2018). These all areas of mathematics are useful for humanity; as the application of these areas enables other subjects useful for humanity. In the present study, only one area of mathematics; arithmetic is considered. Metacognition is a regulatory system that helps individuals to control their cognitive process. It enables students to comprehend mathematical idea and to apply them accurately. Momentarily, metacognition is referred to as thinking about thinking (Brehmer et al., 2016; Polya, 2007; Schneider, 2008). Students use different metacognitive strategies as useful approaches for the solution of the mathematical problem with reasoning.

Think aloud, planning, monitoring and evaluation are used as effective metacognitive strategies in the teaching and learning of mathematics. These strategies are considered as brainstorming strategies for the students (Kramarski, 2008; Bray & Schatz, 2013; Lan, 2005; Schneider, 2008; Sperling et al., 2002). In the think-aloud strategy, students articulate their mathematical ideas during the solution of mathematical problems. In planning strategy, students plan how to complete their tasks. In the next phase, the students monitor their activities to complete the tasks and view the progress of their activities. In the evaluation strategy, the students evaluate the effectiveness of their strategies to complete the tasks (Kani & Shahril, 2015). Several studies have been conducted in different countries of the world to assess the effect of metacognition on mathematical reasoning.

Kramarski and Mevarech (2003) conducted an experimental study to assess the effect of metacognition on the development of mathematical reasoning. Their study was experimental and collaborative settings were arranged for the intervention. Participants of the study received intervention in the form of metacognitive strategies. The study revealed a positive significant effect on the development of mathematical reasoning. Clarke et al. (2012) also conducted an experimental study to assess the development of mathematical reasoning through metacognition. They found that after getting the metacognitive training, the students performed well and got more score in the test of mathematical reasoning. Lestari and Jailani (2018) also conducted an experimental study to find the effect of metacognition on the development of mathematical reasoning. They also found a positive effect of metacognition on the development of mathematical reasoning.

III. Methodology and Design of the Study

The present study was quantitative and experimental. A quasi-experimental design with a pre-test post-test non-equivalent control design was used for the study. Participants of the study were the grade 9 students of a government boys school in Lahore city. Two intact groups of the students were randomly taken as the control group and experimental group. Since randomization is not allowed in the regular classrooms of government schools; therefore, a quasi-experimental design was considered suitable for the study. A validated and reliable research instrument was developed by the researcher.

The experimental group received intervention in the form of metacognitive teaching strategies. Think aloud; planning, monitoring and evaluation strategies were used as metacognitive strategies in the study. During the intervention to the experimental group, the researcher modelled the metacognitive teaching strategies in the teaching of mathematics. After that, the participants of the experimental group were asked to apply these strategies in solving mathematical problems. These metacognitive strategies were applied by the researcher in collaborative settings while teaching. Participants of the study also applied these strategies in collaborative settings. Participants of the control group did not receive the intervention in the form of metacognitive strategies. They were taught with traditional teaching strategies commonly used in Pakistani classrooms.

Since intact groups were selected for the study; therefore, the threat of reactive arrangements was controlled. Participants of the study were of the same characteristics. Therefore, threats of history, maturation, testing and instruments were controlled. Before the start of the intervention, pre-tests were conducted for the control group and experimental group. The same pre-test was given to the participants of the control group and experimental group. The intervention for the experimental group and control group lasted for 16 weeks. After the completion of the intervention, post-tests were conducted for the participants of the control group and experimental group. The same post-test was given to the participants of the control group and experimental group. A scoring rubric was developed for the scoring of pretest and posttest. There was a total of 8 marks for one test item. Students were awarded 2 marks for giving the correct and complete answer of each option of the item; and for false or no answer, zero marks were awarded. The data collected in pre-test and post-test were analyzed by applying an independent samples t-test through a computer software; statistical package for social sciences (SPSS).

IV. FINDINGS

An independent samples t-test was applied on pre-test and post-test scores of participants of the control group and experimental group. Independent samples t-test is applied to compare the mean scores of two groups; if the groups are independent of each other (Rovai et al., 2014). The control group and experimental group of the study are independent of each other. Therefore, independent samples t-test was applied to assess the effect of metacognition on mathematical reasoning after comparing the mean score of the control group and experimental group. Results of data analysis of pre-test and post-test of the control group and experimental groups are described in the following tables 1, 2 and 3.

Table 1

Average Pre-test scores of Control Group and Experimental Group

Content	*Group*	*N*	*M*	*df*	*SD*	*t*	*P(2-tailed)*
Arithmetic	Control	37	3.39	69	1.01	-.344	.94
	Experimental	34	3.48		1.03		

Table 1 shows the comparison of mean scores of the control group and experimental group in the pre-test. The average score of the control group (M=3.39, SD=1.01) and experimental group (M= 3.48, SD=1.03) for $t(69)$= -.344 and P=.94(2-tailed) indicates no significant difference between average pre-test scores of the control group and experimental group. No group performed significantly better than the other group.

Table 2

Average post-test scores of control group and experimental group

Content	*Group*	*N*	*M*	*df*	*SD*	*t*	*P(2-Tailed)*
Arithmetic	Control	37	4.79	69	.44	-.30.62	.000
	Experimental	34	7.58		.30		

Table 2 shows the comparison of average scores of the control group and experimental group. The results of the control group (M=4.79, SD=.44) and experimental group (M=7.58, SD= .30) for $t(69)$= -30.62 and P=.000(2-tailed) indicated a significant difference between average scores of the control group and experimental group for post-test. Participants of the experimental group got more scores as compared to the participants of the control group. The study did not support the null hypothesis. Therefore, the null hypothesis that there is no significant effect of metacognition on mathematical reasoning, is rejected. There is a positive significant effect of metacognition on mathematical reasoning among secondary school students.

Table 3

Average gain scores of control group and experimental Group

Content	*Group*	*N*	*M*	*df*	*SD*	*t*	*P(2-tailed)*
Arithmetic	Control	37	1.39	69	1.07	-10.49	.000
	Experimental	34	4.10		1.10		

Table 3 indicates the comparison of average gain scores of the control group and experimental group. The results of the control group (*M*=1.39, *SD*= 4.10) and experimental group (*M*=4.10, 1.10) for $t(69)$= -10.499 and P=.000(2-tailed) indicates that there is a significant difference between average gain scores of the control group and experimental group. The participants of the experimental group got more score as compared to the participants of the control group. The study did not support the null hypothesis. Therefore, the null hypothesis is rejected. Metacognition has a positive significant effect on mathematical reasoning among the participants of the experimental group.

V. Discussion

The study has proved the positive effect of metacognition on mathematical reasoning among secondary school students. The present experimental study was conducted in collaborative settings. The study confirmed that if metacognitive training is provided in collaborative settings; then the students got more scores on a mathematical reasoning test. The present study was conducted in collaborative settings. Metacognitive training was provided for the students. Students share their creative mathematical ideas and explanations and with their teachers in collaborative settings. Metacognitive training enables students to regulate their thought process in the solution of mathematical problems.

The present study has confirmed the development of mathematical reasoning through metacognition among secondary school students in the Pakistani context. The development of mathematical reasoning through metacognition has proved in several countries. The study confirms the findings of Kramraski and Mevarech (2003). They conducted an experimental study in collaborative settings to assess the development of mathematical reasoning through metacognition. Clarke et al. (2012) also conducted an experimental study to assess the development of mathematical reasoning through metacognition. They found that after getting the metacognitive training, the students performed well and goy more scores in the test of mathematical reasoning. The present study also confirms the findings of Lestari and Jailani (2018). They also conducted an experimental study to find the effect of metacognition on the development of mathematical reasoning. They also found a positive effect of metacognition on the development of mathematical reasoning.

VI. Conclusion and Recommendations

It is concluded based on the findings of the study, that metacognition has a positive effect on the development of mathematical reasoning among secondary school students in Pakistan. The development of mathematical reasoning is caused due to the intervention given in the study. The intervention was given in the form of metacognitive strategies and collaborative settings. The environment given to the students provided them with the opportunities to learn from each other and their teachers. They became able to share their ideas and their teachers. Metacognitive strategies enable them to regulate their thought process. Applications of these strategies also enabled the students to apply mathematical ideas in a correct and reasoned way. In the light of findings of the study, it is recommended that metacognitive strategies are helpful in the teaching and learning of mathematics in Pakistan. Application of metacognitive strategies enhances mathematical reasoning among secondary school students. Therefore, secondary school teachers and secondary school students should use metacognitive strategies in teaching and learning of mathematics in Pakistan.

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