The Effect of Instruction in Cognitive and Metacognitive Strategies on Ninth-Grade Students' Metacognitive Abilities

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Abstract

The purpose of this study was to investigate the effect of instruction in cognitive and metacognitive strategies on Taiwanese ninth-grade students' metacognitive abilities. The investigators designed a Metacognitive-Strategy Worksheet (MSW) to promote students' use of cognitive and metacognitive strategies while solving problems. The MSW was developed based on Montague's (1992, 1995, 1997) cognitive-metacognitive strategies for mathematical problem solving. The results of the study indicated that although instruction in cognitive and metacognitive strategies utilizing MSW techniques did not have a statistically significant effect on the ninth-grade students' overall metacognitive abilities, it might have benefited their strategy use.

Keywords: Metacognition; Mathematics

Metacognition plays an essential role in effective mathematical problem solving (Artzt & Armour-Thomas, 1992; Cai, 1994; Garofalo & Lester, 1985; Mayer, 1987; Schoenfeld, 1985, 1987, 1989, 1992). Schoenfeld (1985) indicated that students usually did not recognize or select appropriate approaches to problems when solving mathematical problems. Rather, they often "adopt what initially seems like a reasonable approach to a problem and then proceed to follow it without further evaluation of their decision as long as they are able to keep working" (Charles, Lester, and O'Daffer, 1987, p. 10). Metacognition involves a variety of decisions and strategies such as monitoring and selecting. If students are unable to monitor or make decisions, they will not learn mathematics successfully. As indicated by Kroll and Miller (1993), lack of metacognitive skills is one of the major factors that cause students' difficulties with mathematics.

Studies have shown that metacognitive skills can be learned (Campione, Brown, & Connell, 1989; Garofalo, 1987; Lester, 1989), and that students who have better metacognitive abilities perform better in mathematical problem solving (Artzt & Armour-Thomas, 1992; Carpenter & Fennema, 1996; Lambdin, 1993). They devise solution plans before starting to solve problems. When they get stuck with problems, they reflect, pose alternatives, and choose among them. Metacognition is important in students' mathematics learning because it affects their acquisition, comprehension and application of what is learned (Wilson, 1999). Thus, developing students' metacognitive abilities should help them improve their mathematical abilities. Consequently, it is important to develop instructional activities that enhance students' metacognitive abilities in mathematics classrooms.

The purpose of this study was to investigate the effect of the use of a Metacognitive-Strategy Worksheet (MSW) on ninth-grade students' metacognitive abilities. The MSW was developed based on Montague's (1992, 1995, 1997) cognitive-metacognitive strategies for

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mathematical problem solving and was used to aid students in solving mathematical problems during instruction in cognitive and metacognitive strategies. Montague's cognitive-metacognitive strategies for mathematical problem solving have been shown to improve metacognitive abilities of students with learning disabilities. However, little has been done to develop instructional procedures for average students based on these cognitive-metacognitive strategies for mathematical problem solving and to investigate the effect of such instructional procedures on average students' metacognitive abilities. This study investigated how the use of Montague's strategies affects average students' metacognitive abilities.

The subjects for this study comprised two ninth-grade classes, the experimental class and the control class, in Taiwan. The experimental class received instruction in cognitive and metacognitive strategies utilizing MSW techniques, and the control class received traditional instruction. The specific questions addressed by this study included:

1. What relationship is there between students' metacognitive ability on the pre- and posttests in the control class?
2. What relationship is there between students' metacognitive ability on the pre- and posttests in the experimental class?
3. What is the relationship between students' metacognitive ability in the control and experimental classes?

Theoretical Basis

Montague's (1992, 1995, 1997) cognitive-metacognitive model of mathematical problem solving served as the foundation for this study. Montague described mathematical problem solving in a series of seven cognitive processes: comprehending problem information (read), paraphrasing problems in one's own words (paraphrase), visualizing problems through illustrations (visualize), hypothesizing solution plans (hypothesize), estimating answers (estimate), computing solutions (compute), and checking every step of the solution (check). Building on the idea that metacognitive processes not only focus on self-awareness of cognitive knowledge but also direct and regulate cognitive processes during problem solving, Montague identified three metacognitive activities associated with each cognitive process: self-instruction, self-questioning, and self-monitoring. In self-instruction, students are involved in identifying and directing problem solving strategies before execution. Self-questioning involves internal dialogue for regulating execution of cognitive strategies. Self-monitoring encompasses appropriate use of strategies and encourages students to monitor their performance (Montague, 1992).

Montague and Bos (1986) found that cognitive-metacognitive strategy instruction is effective in improving mathematical problem solving for secondary students with learning disabilities. Further, she found that coordinated use of both cognitive and metacognitive strategies for mathematical problem solving was more effective for middle school students with learning disabilities than either cognitive or metacognitive strategies alone (Montague, 1992). However, it is not clear whether instruction in cognitive and metacognitive strategies has the same effect for average students' metacognitive abilities. In order to investigate the effect of such instructional procedures on average students' metacognitive abilities, it would be worthwhile to develop instructional procedures in cognitive and metacognitive strategies for average students. In the present study, MSWs were used to support students' engagement with cognitive and metacognitive strategies for mathematical problem solving during the MSW instruction. The MSW instructional procedures were developed based on Montague's (1992, 1995, 1997) cognitive-metacognitive model of mathematical problem solving.

Method

Subjects

Forty-five students from two intact ninth-grade classes in a suburban junior high school in Taiwan (R.O.C.) participated in this study. One class served as the experimental class, and the other class served as the control class. There were twenty-seven students in the experimental class and eighteen students in the control class. One of the investigators served as the instructor for both classes.

Materials and Instruments

Metacognitive-strategy worksheets. A metacognitive-strategy worksheet (Figure 1) was developed based on Montague's (1992, 1995, 1997) cognitive-metacognitive strategies for mathematical problem solving. The MSW was only used in the experimental class to encourage students to use cognitive and metacognitive strategies to solve mathematical problems. The worksheet consisted of seven sections based on Montague's seven cognitive processes: read, paraphrase, visualize, hypothesize, estimate, compute, and check. In each section, students were required to describe their self-instruction, self-questioning, and self-monitoring activities in the Descriptions column on the worksheets. They were also asked to make a mark, corresponding to each process, on the worksheets after checking.

Processes	Descriptions	Please mark * after checking.
Read	What does this problem mean?	
Paraphrase	What is known? What is unknown?	
Visualize		
Hypothesize		
Estimate		
Compute		
Check	Please mark * in the correspondence box to each process after you have checked the process.	

Figure 1. Sample of the Metacognitive-Strategy Worksheet

Instructional procedures. The teacher, who was one of the investigators, implemented MSW techniques in the experimental class and traditional instruction in the control class. Since MSW was an attempt to integrate cognitive and metacognitive strategies into regular mathematics classes, it was incorporated into the regular school system instructional materials which were already being used in the experimental class. In both classes, the mathematical content of the regular instructional materials was probability.

A total of twenty-seven students participated in the instruction in cognitive and metacognitive strategies utilizing MSW techniques for fifty minutes, five days a week for a period of two weeks. Before the study began, the teacher introduced students to the purpose and procedures of the study. The pretest was administered by the teacher to all subjects in order to assess their metacognitive abilities before they received either the MSW instruction or traditional instruction.

During each experimental class session, the teacher demonstrated to the students how to use Montague's (1992, 1995, 1997) cognitive-metacognitive strategies to solve mathematical problems. The students were then asked to do practice problems using the MSWs. The MSWs required students to use Montague's cognitive-metacognitive strategies to solve mathematical problems. After students started to work on the MSWs, the teacher moved around the classroom to help them, but her role was only to facilitate their use of Montague's cognitive-metacognitive strategies.

After they were graded, the worksheets were given back to the students in the following class. During that class, the teacher gave positive and corrective feedback to the class. When the students understood how to improve their use of MSWs, the teacher proceeded to continue her MSW instruction to the class. After the MSW instructional procedures, the posttest was administered to both the experimental and control classes by the teacher.

Metacognition Inventory. The Metacognition Inventory developed by Lin and Chang (1993) was used as the pretest and posttest instrument to assess students' metacognitive abilities in this study. Each student was given the pretest before and the posttest after they received either instruction in cognitive and metacognitive strategies or traditional instruction.

The inventory consists of six sub-inventories: attention focusing, information organizing, strategy use, self-evaluation, self-monitoring, and self-repair. In attention focusing, students are involved in assessing and focusing on what is being learned. Information organizing involves organizing information, conditions, and knowledge. Strategy use involves selecting, combining, and coordinating general and specific strategies. In self-evaluation, students are involved in evaluating their mathematical knowledge. Self-monitoring involves monitoring one's state of mathematics learning or progress of solution plans. Self-repair involves altering one's mathematics learning approaches. Cronbach's alpha for each sub-inventory ranged from 0.8411 to 0.8743, and the split-half reliability of each sub-inventory ranged from 0.8490 to 0.8719.

A four-point Likert scale was used in each sub-inventory. Four points were given when the student chose "Much like her/himself", three points were given when the student chose "A bit like her/himself", two points were given when the student chose "A bit not like her/himself", and one point was given when the student chose "Not like her/himself at all". A total score was computed for each student by adding up points of each response in each of the six sub-inventories. Higher scores represent higher metacognitive abilities based on the inventory.

Data Analysis

The data for this study consisted of students' attention-focusing, information-organizing, strategy-use, self-evaluation, self-monitoring, self-repair, and metacognitive-ability scores on the pretest and posttest, where metacognitive-ability scores were obtained by adding up the scores of the six sub-inventories. Descriptive statistics and *t*-test analyses were used to examine differences between these scores on the pretest and posttest. ANCOVA was conducted on metacognitive-ability scores to detect statistically significant differences between the experimental and control classes.

Results

For both the experimental and control classes, scores on the pretest were compared to scores on the posttest. As shown in Tables 1 and 2, the mean strategy-use scores increased from pretest to posttest for both classes. In the control class, the strategy-use mean for the pretest was 19.94 and the mean for the posttest was 20.61, an increase of 0.67 points. In the experimental class, the mean increased 1.63 points from 18.07 to 19.70. The difference between pretest and posttest scores was significant for the experimental class (p=0.004), but not for the control class. There were no statistically significant differences between pretest and posttest mean scores for the attention focusing, information organizing, strategy use, self-evaluation, self-monitoring, and self-repair sub-inventories in either class.

Table 1
Strategy-Use Scores of the Control Class

Strategy-use Scores	Mean	Std. Deviation	*t*	p
Pretest	19.94	5.60	-0.656	0.521
Posttest	20.61	5.61		

Table 2
Strategy-Use Scores of the Experimental Class

Strategy-use Scores	Mean	Std. Deviation	*t*	*p*
Pretest	18.07	6.34	-3.198	0.004
Posttest	19.70	6.41		

There was an increase in mean metacognitive-ability score for each class. In the control class, the mean for the pretest was 114.11 compared to the mean score of 118.28 for the posttest. In the experimental class, the mean for the pretest was 106.44 and the mean for the posttest was 110.96, a larger increase than the control class. However, these increases were not statistically significant. As shown in Tables 3 and 4, *t*-test analyses showed that in either class, students' metacognitive-ability scores were not, on average, significantly different between the pretest and posttest.

Table 3
Metacognitive-Ability Scores of the Control Class

Metacognitive-ability Scores	Mean	Std. Deviation	*t*	*p*
Pretest	114.11	25.14	-1.027	0.319
Posttest	118.28	26.04		

Table 4
Metacognitive-Ability Scores of the Experimental Class

Metacognitive-ability Scores	Mean	Std. Deviation	*t*	*p*
Pretest	106.44	29.04	-1.784	0.086
Posttest	110.96	29.88		

Since homogeneity of regression was assumed (see Table 5), ANCOVA was performed to determine if the posttest metacognitive-ability scores of the two classes differed significantly from one another. Again, there was no statistically significant difference between the posttest metacognitive-ability scores of the experimental and the control classes (see Table 6).

Table 5
Summary of Test for Homogeneity of Regression

	SS	DF	MS	*F*	*p*
Group*Pretest	112.168	1	112.168	0.511	0.479

Table 6
Summary of ANCOVA

	SS	DF	MS	*F*	*p*
Group	2.925	1	2.925	0.013	0.908

Discussion

How might the instruction with MSWs been related to the increase in the experimental class mean score on strategy use? The MSW instructional technique was intended to provide a way for each student in the experimental class to self-instruct, self-question, and self-monitor while following each of the seven steps to solve problems. Examining the individual MSWs, most students in the experimental class completed each of the seven steps on the worksheets when they solved problems. Because strategy use involves selecting, combining, and coordinating general and specific strategies such as paraphrasing and drawing, the Paraphrase and Visualize components of the MSW may have helped students in the experimental class develop their strategy use, significantly increasing their strategy use scores. Figure 2 shows a sample of one experimental class student's responses on an MSW. The mathematical problem for this MSW was as follows: There are 20 cards numbered 1 to 20. A card is drawn at random from the 20 cards. (1) Find the probability that the card shows a prime number. (2) Find the probability that the card shows a multiple of 2. (3) Find the probability that the card shows a number whose last digit is 7. As shown in this sample, the student identified the key points of the problem in his own words in the Paraphrase section, and then listed the possible drawn cards to find the solutions in the Visualize section, which might have supported his strategy use during the problem solving process.

Processes	Descriptions	Please mark * after checking.
Read	What does this problem mean? 20 cards, prime numbers, multiples of 2, numbers with the last digit of 7… What is the probability?	*
Paraphrase	What is known? 20 cards in total What is unknown? the number of prime numbers, the number of multiples of 2, the number of numbers with the last digit of 7	*
Visualize	1. 1, ②, ③, 4, ⑤, 6, ⑦, 8, 9, 10, ⑪, 12, 13, 14, 15, 16, ⑰, 18, ⑲, 20 2. 1, ②, 3, ④, 5, ⑥, 7, ⑧, 9, ⑩, 11, ⑫, 13, ⑭, 15, ⑯, 17, ⑱, 19, ⑳ 3. 1, 2, 3, 4, 5, 6, ⑦, 8, 9, 10, 11, 12, 13, 14, 15, 16, ⑰, 18, 19, 20	*
Hypothesize	$\frac{\text{the number of elements in the event}}{\text{the total number of all elements}}$ 1. 8/20 2. 10/20 3. 2/20	*
Estimate	1. $0<x<1$ $0<x<1/2$ 2. $0<y<1$ Not big, not small 3. $0<z<1$ very small	*
Compute	1. 4/10=2/5 2. 10/20=1/2 3. 2/20=1/10	*
Check	Please mark * in the correspondence box to each process after you have checked the process.	*

Figure 2. Sample of a student's responses in the experimental class

Conclusion

This study provides a glimpse of how instruction in cognitive and metacognitive strategies utilizing MSW techniques can influence ninth-grade students' metacognitive abilities. Although previous research has suggested that instruction in cognitive and metacognitive strategies is helpful for students with learning disabilities, this study addresses whether such instruction is also beneficial for average students. The results suggest that instruction in cognitive and metacognitive strategies utilizing MSW techniques may not have a broad effect on ninth-grade students' metacognitive abilities. However, MSW-based instruction may benefit students' strategy use. Strategy use is an important element of metacognition contributing to successful problem solving (Davidson & Sternberg, 1998). Further studies on the relationship between MSW-based instruction and students' strategy use should be undertaken to better understand the effect of MSW-based instruction on students' strategy use.

In future research, the methods of this study should be implemented over a longer period, with a larger group of students, or with other classroom teachers. This would help to determine the effectiveness of instruction in cognitive and metacognitive strategies in improving students' metacognitive abilities. It also would be beneficial to develop other techniques in addition to MSWs to integrate cognitive and metacognitive strategies into regular classroom teaching with average students.

References

Artzt, A. F., & Armour-Thomas, E. (1992). Development of a cognitive-metacognitive framework for protocol analysis of mathematical problem solving in small groups. *Cognition and Instruction*, *9*(2), 137-175.

Cai, J. (1994). A protocol-analytic study of metacognition in mathematical problem solving. *Mathematics Education Research Journal*, *6*, 166-183.

Campione, J. C., Brown, A. L. & Connel, M. L. (1989). Metacognition: on the importance of understanding what you are doing. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving.* Reston, VA: National Council of Teachers of Mathematics.

Carpenter, T & Fennema, E. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education, 27*(4), 403-434.

Charles, R. I., Lester, F., & O'Daffer P. (1987). *How to evaluate progress in problem solving*. Reston, VA: National Council of Teachers of Mathematics.

Davidson, J. E., & Sternberg, R. J. (1998). Smart problem solving: How metacognition helps. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 47-68). Mahwah, NJ: Lawerence Erlbaum Associates.

Garofalo, J. (1987). Metacognition and school mathematics. *Arithmetic Teacher, 34*(9), 22-23.

Garofalo, J. & Lester, F. (1985). Metacognition, cognitive monitoring, and mathematical performance. *Journal for Research in Mathematics Education, 16*, 163-176.

Kroll, D. L. & Miller, T. (1993). Insights from research on mathematical problem solving in the middle grade. In D. Owens (Ed.) *Research ideas for the classroom: Middle grade mathematics* (pp. 8-27). Reston, VA: NCTM.

Lambdin, D. V. (1993). Monitoring moves and roles in cooperative mathematical problem solving. *Focus on Learning Problems in Mathematics, 15*(2&3), 48-64.

Lester, F. K. (1989). Mathematical problem solving in and out of school. *Arithmetic Teacher, 37*(3), 33-35.

Lin, C. S. & Chang, C. Y. (1993). A study of the relationship between junior high school students' metacognition, motivational belief, and mathematics problem-solving strategies. *Bulletin of Educational Psychology, 26*, 53-74. (In Mandarin)

Mayer, R. E. (1987). *Educational psychology.* Boston: Little, Brown and Co.

Montague, M., & Bos, C. (1986). The effect of cognitive strategy training on verbal math problem solving performance of learning disabled adolescents. *Journal of Learning Disabilities*, *19*, 26-33.

Montague, M. (1992). The effects of cognitive and metacognitive strategy instruction on mathematical problem solving of middle school students with learning disabilities. *Journal of Learning Disabilities*, *25*, 230-248.

Montague, M. (1995). Cognitive instruction and mathematics: Implications for students with learning disorders. *Focus on Learning Problems In Mathematics, 17*(2), 39-49.

Montague, M. (1997). Cognitive strategy instruction in mathematics for students with learning disabilities. *Journal of Learning Disabilities, 30*(2), 164-177.

Schoenfeld, A. H. (1985). *Mathematical problem solving.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Schoenfeld, A. H. (1987). What's all the fuss about metacognition? In A. H. Schoenfeld (Ed.), *Cognitive science and mathematics education* (pp. 189-215). Hillsdale, NJ: Lawrence Erlbaum Associates.

Schoenfeld, A. H. (1989). Teaching mathematical thinking and problem solving. In L. B. Resnick & L. E. Klopfer (Eds.), *Toward thethinking curriculum: Current cognitive research.* Alexandria, VA: Association for Supervision and Curriculum Development Yearbook.

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem-solving, metacognition, and sense-making in mathematics. In D. A. Grouws (Ed.), *Handbook on research on mathematics teaching & learning.* New York: Macmillan Publishing Group.

Wilson, J. (1999). The Nature of Metacognition: What do primary school problem solvers do? In D. Barwood, D. Greaves, & P. Jeffery (Eds.), *Teaching numeracy and literacy: Interventions and strategies for "at risk" students* (pp. 283-294). Coldstream, Victoria: Australian Resource Educators' Association.