Metacognitive Intervention in a Cognitive-apprenticeship-computer-based Environment

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This paper reports on a strand of a larger investigation into the effect of metacognitive training on 11 to 12-year-old students' mathematical word problem solving in a cognitive-apprenticeship-computer-based environment. Empirical results from the quasi-experimental and case study designs suggested that treatment students outperformed control students on the ability to solve word problems on their individual written measures and collaborative "think aloud" interactions in a computer environment. Moreover, treatment students in the case study elicited more well-regulated metacognitive decisions compared with control students.

Research that focuses on metacognition in mathematics education are often studied in a non-computer environment (e.g., Kramarski, Mevarech, & Arami, 2002; Goos & Galbraith, 1996). It is only recently that attempts have been made to employ metacognitive training within computer environments (Kramarski & Ritkof, 2002; De Corte, Verschaffel Lowyck, Dhert, & Vandeput, 2000). For example, De Corte et al. (2000) designed a computer-supported collaborative learning environment in which upper primary school children were guided and supported in becoming more strategic, motivated, communicative, mindful, and self-regulated mathematical problem solvers and problem posers. They reported that the learning environment had a significant positive effect on the problem solving competency of sixth graders but not of the fifth graders. In addition, teachers who were involved in the study also voiced their appreciation of the learning environment: the approach to the teaching of problem solving as well as the use of a "Knowledge Forum" as a supporting tool for learning.

A cognitive-apprenticeship model of instruction was also identified by Schoenfeld (1992) and Verschaffel et al. (1999) that might promote students' ability to self-regulate during problem solving. These studies were again undertaken in classrooms where the computer was not used. In Looi and Tan's study (1998), *WordMath*, a software designed on the instructional approach of cognitive apprenticeship methodology, was used as a tool for students to solve word problems that are particular to the Singapore mathematics curriculum. This software was tested on thirty-six 11 to 12-year-olds from two Singapore schools. The researcher noted that some of the pedagogical domains in *WordMath* allowed pupils to explore and also encourage them to exhibit metacognitive behaviours. However, the researchers failed to address explicitly how the students' cognitive skills in the cognitive apprenticeship mode of instruction helped them in their word problem solving.

The present study examines the extent to which metacognitive training could promote metacognitive behaviours of students solving word problems in *WordMath* environment. (Refer to http://math.nie.edu.sg/skteong/WordMath.doc for details of WordMath.)

Method

The study adopted a two-phase design, combining a quasi-experimental design and a case study design. The quantitative study's quasi-experimental design allowed the author

to examine the effect of metacognitive training on students' mathematical word problem solving performance before, immediately after, and then a prolonged period after the metacognitive training. In a complementary fashion, the qualitative study allowed the author to obtain a deeper or richer sense of how metacognitive decisions influenced students' mathematical word problem solving performance where "pair think aloud" protocols were used to elicit qualitative information.

Four classes of Primary 6 (11-12 years old) students from two schools were involved in this intensive study over a period of eight weeks. Students of the four classes were assigned to two conditions: treatment group where students received metacognitive training with *WordMath* (T); and a control group where students did not receive metacognitive training with *WordMath* (C). Treatment and control students in both schools were then ranked and stratified into higher achievers (HA) and lower achievers (LA) according to their end-of-the-year school mathematics examination results.

The metacognitive intervention involved the use of CRIME (Teong, 2003), a metacognitive strategy developed by the author. CRIME is an acronym of the word problem solving stages: Careful reading; Recall possible strategies; Implement possible strategies; Monitor; and Evaluate. At each stage of the word problem solving, there are questions to direct the students to regulate and monitor their solution. The use of CRIME was piloted on two students, and CRIME was found to be an effective strategy to make students become aware of their cognitive processes during word problem solving. In this study, students solved word problems in *WordMath* environment with the metacognitive strategy, CRIME.

For the quasi-experimental design, students from all the classes took a written pre-test consisting of ten word problems on the topics Number and Fractions. A written post-test was administered after the students had undergone two weeks of intervention. Altogether, there were four training sessions and each session was delivered by the author, and consisted of a set of learning instructions with some word problem tasks. A final delayed post-test was administered a month after the posttest.

In addition, a pair of higher achievers and a pair of lower achievers were selected from each class from the two schools for the case study design. They underwent two extra training sessions where they solved four word problems during each session. Their word problem solving behaviours were video-recorded but not analysed at this stage. After these sessions, the pairs of students' "think aloud" protocols of four word problems were video-recorded, and these data were analysed. Six weeks after the post-test, due to logistics and time constraints, only the treatment higher and lower achievers were granted permission to participate in this case study design.

Analysis and Results

Quantitative Analysis

Scores obtained from the students' written word problem solving tests were analysed. Table 1 shows the means and standard errors of the students' scores on the three tests. As the groups were different in the pre-test scores, this table also shows the adjusted data for the post-test and delayed post-test scores when the pre-test scores were used as the covariate.

A repeated measures two-way analysis of covariance with the pre-test as a covariance was generated to analyse the data and the results indicated that metacognitive training had a significant influence on the students' word problem solving performance ($F=7.812$,

p<0.05). However, there was not significant interaction at the 5% level between metacognitive training and mathematical achievement (F=1.96, p>0.05).

Table 1

Means and Standard Errors of Students' Achievements Before and After Adjustments

Meta-cognitive Training	Mathematical Achievement		Before Adjustment			After Adjustment, evaluated at covariate of pre-test = 3.27	
			Pre-test Scores	Post-test Scores	Delayed Post-test Scores	Post-test 1 Scores	Delayed Post-test 1 Scores
Treatment	HA	Mean	4.56	5.88	7.12	5.01	6.33
		N	25	25	25	25	25
		Std Error	2.83	2.42	2.32	0.35	0.33
	LA	Mean	2.36	3.16	4.12	3.77	4.68
		N	25	25	25	25	25
		Std Error	2.41	2.58	2.55	0.35	0.32
Control	HA	Mean	3.40	4.04	5.04	3.95	4.96
		N	25	25	25	25	25
		Std Error	2.50	2.52	1.84	0.34	0.32
	LA	Mean	2.76	3.12	3.88	3.46	4.19
		N	25	25	25	25	25
		Std Error	1.54	1.67	1.74	0.34	0.32

Qualitative Analysis

A further analysis was undertaken to try to identify the differences between types of word problem solving behaviours shown by the selected pairs of higher and lower achievers. The following shows the analysis procedure applied to one of the four word problem solving protocols for each pair of students.

Problem: Joe Ee, Mun Fai and Jing Hao shared 400 marbles amongst themselves. Joe Ee received 28 marbles. Jing Hao received seven times the total number of marbles Joe Ee and Mun Fai received. How many more marbles did Jing Hao receive than Mun Fai?

Think Aloud Protocol Framework. A modified Artzt and Armour-Thomas' framework (1992) was used to analyse students' think aloud protocols while solving word problems with *WordMath*. The original framework had eleven episodes to partition group think aloud protocols. The author modified this framework for highlighting major strategic decisions made by pairs of students. One of the major modifications was to eliminate the category "Watch and listen". In Artzt and Armour Thomas' framework, this category was for students who were not involved in group problem solving discourse. In the present study, continual verbal interactions were evident between students during word problem solving. Each student was also involved in either typing or controlling the mouse. The behaviours, described in Teong (2000) were: reading (cognitive); analysis (metacognitive); exploration (cognitive or metacognitive); planning (metacognitive); implementation (cognitive or metacognitive); and verification (cognitive or metacognitive). The inter-rater

reliability coefficient for the four word problems was 0.86 (Teong, 2000, p. 76). The overall structures of the solution analysis of students S1 and S2 (T/HA), S3 and S4 (T/LA), S5 and S6 (C/HA), and S7 and S8 (C/LA) are illustrated in the following Figures 1, 2, 3 and 4 respectively.
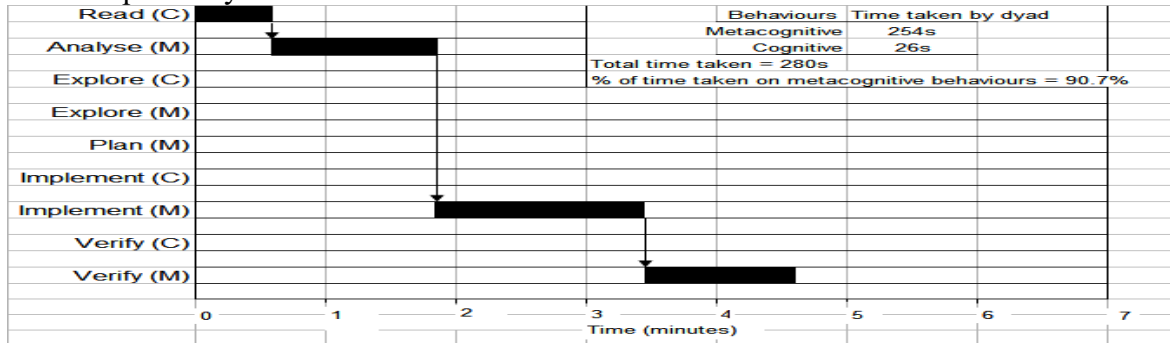

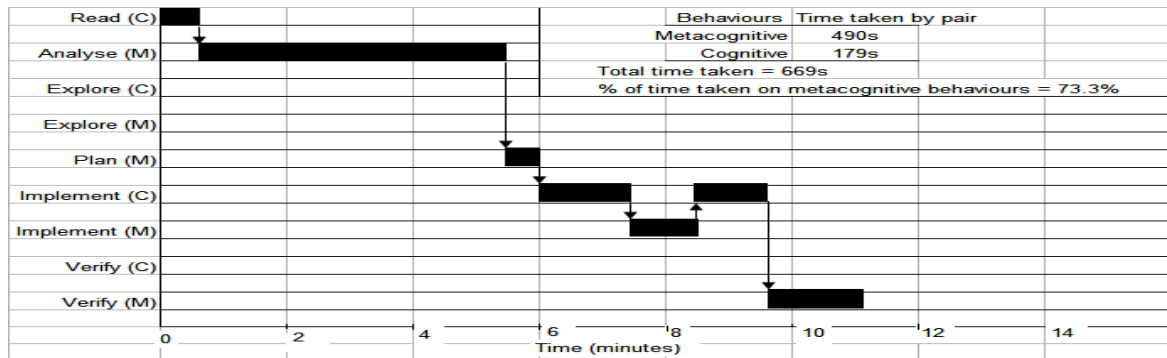*Figure 1.* A timeline representation of S1 and S2 (T/HA) solving MARBLE.

Figure 2. A timeline representation of S3 and S4 (T/LA) solving MARBLE.
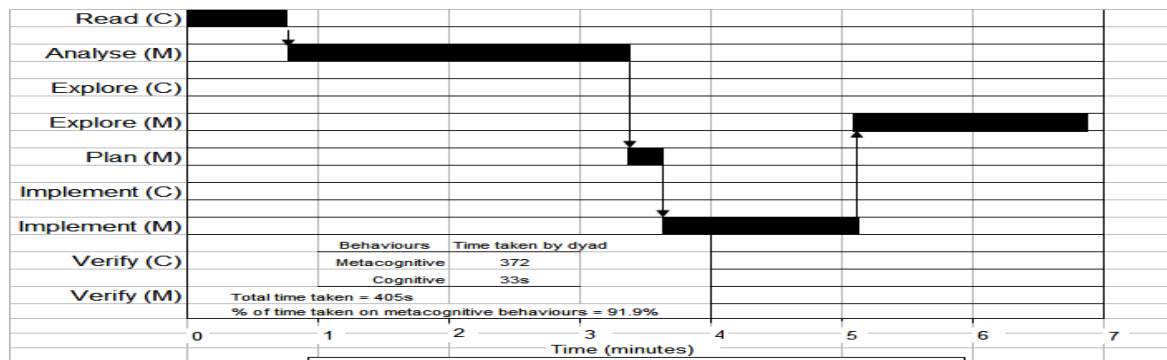

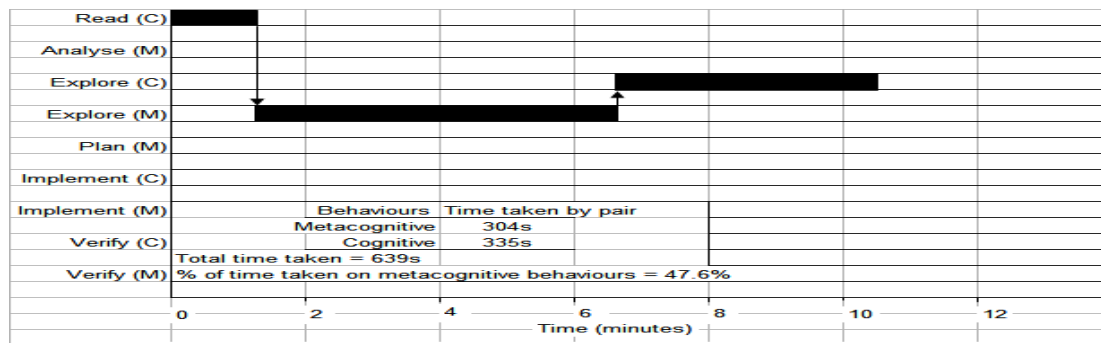*Figure 3.* A timeline representation of S5 and S6 (C/HA) solving MARBLE.

Figure 4. A timeline representation of S7 and S8 (C/LA) solving MARBLE.

Summary of Students' Progression of Word Problem Solving Activity. The protocol of S1 and S2 (T/HA) (see Figure 1) in post-test and delayed post-test could be summarised as a well-regulated progression of activity, Read → Analyse → Implement (metacognitive) → Verify (metacognitive). Analysis of S1 and S2's protocols revealed that they were consistently focused, goal driven, well-regulated and explicit in their decision making. They appeared to be satisfied only when they had checked that their solution satisfied the conditions of the word problem. These strengths appeared to have contributed to their success in their word problem solving.

The protocol of S3 and S4 (T/LA) (see Figure 2) during post-test could be summarised as a well-regulated progression of activity, Read → Analyse → Plan → Implement (cognitive) → Implement (metacognitive) → Implement (cognitive) → Verify (metacognitive), which led to their success in solving the word problem. They also seemed in control of their cognitive actions, as illustrated by the following exchange after the pair had drawn the diagram that represented the MARBLE word problem.

S3: The question asked how many more marbles did Jing Hao receive than Mun Fai.

S4: So we have to find Mun Fai.

S3: Let me see (pauses for 3 seconds). This is the unknown (pointing to the diagram)/ unknown because of Mun Fai. So let say this is one small unit/

S4: Okay.

These strengths contributed to their success in all their word problem solving during the post-test and delayed post-test.

S5 and S6's (C/HA) word problem could be summarised as an orderly progression of activity, Read → Analyse → Plan → Implement (metacognitive) → Verify (metacognitive) during posttest. They consistently demonstrated their ability to analyse the word problem coherently by drawing diagrams to show the relationship between the facts of the word problem situation. They appeared to regulate their decisions in their word problem solving which led to their success in most of their word problem solving. However, they were unsuccessful in solving the MARBLE word problem.

The protocol of S7 and S8 (C/LA) (see Figure 4) could be summarised as:

1. Read the word problem.

2. Explore (cognitive), where the pair was observed to take the numbers out of the word problem context and used different operations to manipulate these numbers.

S7 and S8 appeared to have limited resources to help them in their word problem solving. They engaged in exploration and tried making local assessments at the beginning

of the word problem solving sessions, but their metacognitive decisions were weak and they did not help them. With respect to the MARBLE word problem, they devoted 47.6% of their time to metacognitive activities. This pair was successful in 25% of their word problem solving in post-test.

Numerical Representation of Higher and Lower Achievers' Protocol Data. The following table, Table 2, demonstrates the time higher and lower achievers devoted to cognitive and metacognitive behaviours during post-test and delayed post-test for the MARBLE word problem.

Table 2

Time in Seconds (and %) Devoted to Cognitive and Metacognitive Behaviours Per Pair for MARBLE Word Problems During the Post-Test and Delayed Post-Test

Behaviour Category	Posttest				Delayed Posttest	
	S1 & S2 (T/HA)*	S3 & S4 (T/LA)*	S5 & S6 (C/HA)	S7 & S8 (C/LA)	S1 & S2 (T/HA)*	S3 & S4 (T/LA)*
Metacognitive	254 (90.7)	490 (73.3)	372 (91.9)	304 (47.6)	381 (94.8)	612 (95.9)
Cognitive	26 (9.3)	179 (26.8)	33 (8.1)	335 (52.4)	21 (5.2)	26 (4.1)
Total	280(100)	669(100)	469(100)	639(100)	402(100)	638(100)

Note. * indicates correct solution.

The results in Table 2 appear to indicate that treatment lower achievers devoted more time to metacognitive behaviours compared with control lower achievers. For example, S3 and S4 (T/LA) devoted 73.3% and 95.9% of their time to metacognitive activities during post-test and delayed post-test respectively compared with S7 and S8 (C/LA) who devoted 47.6% of their time to metacognitive activities during post-test.

Discussion

Empirical evidence from the quasi-experimental design supports the potential of metacognitive training on the mathematical word problem solving performance of higher and lower achievers in a cognitive-apprenticeship-computer-based environment. The findings concur with results of previous studies that focused primarily on the effects of metacognitive training on problem solving in a non-computer environment (Verschaffel et al., 1999). A possible reason why metacognitive training may result in a greater improvement in mathematical word problem solving performance may be attributed to the 'explicitness' in the pedagogical approach and relative 'completeness' (Mevarech & Kapa, 1996) of the computer environment with CRIME during word problem solving. Specifically, questions in CRIME guided students to connect ideas to their prior knowledge, analyse information, and to self-monitor their progress by assessing and correcting their mistakes. For example, S1 and S2 (T/HA) demonstrated the metacognitive components in CRIME when they solved the MARBLE word problem. They read the word problem carefully, referring to the word problem situation again when needed; they recalled that the model approach would help them solve this word problem and started

drawing the appropriate diagram; they implemented their strategies once they had drawn the models that depicted the word problem situation; they monitored and regulated their word problem solving while drawing the models and implementing their strategies; and finally they engaged in evaluation where they used a test to ascertain that the solution met all the conditions in the word problem. In contrast, the control students were not so intense in their approach to solving the word problem with their own metacognitive strategies (if present) as illustrated in CRIME.

In addition, there were three factors that indicated why the classroom environment was considered as 'complete'. First, the intervention approach engaged treatment students in all aspects of word problem solving identified in the Singapore mathematics curriculum, including the nature of the word problems, representation used for those word problems, strategy selection, and cognitive monitoring. Next, both the modeling and scaffolding teaching methods also allowed the full tasks during the sessions to be perceived by the students. Finally, the social aspect of learning was considered. Children worked in pairs and were encouraged to solve word problems collaboratively, focusing on CRIME processes.

The analysis of transcripts of collaborative word problem solving of the students, using the modified Artzt and Armour-Thomas' framework also revealed that students who had metacognitive training were in control of their word problem solving behaviours as shown in their high percentage of metacognitive behaviours in post-test and delayed post-test (see Table 2). This often led to their success in word problem solving as shown in S1 and S2 (T/HA) and S3 and S4 (T/LA) word problem solving. The poor performance of S5 and S6 (C/HA), and S7 and S8 (C/LA) word problem solving appeared to stem from the poor techniques employed in solving word problems. According to Mayer (1998), one of the factors that discriminate successful problem solvers from unsuccessful ones is their ability to know not only what to do, but also when to do it with regard to using their cognitive skills. For example, S5 and S6 (C/HA) could not solve the MARBLE word problem though they devoted 91.9% (see Table 2) to metacognitive activities. Visual inspection of S5 and S6 (C/HA) word problem solving suggested that they had misdirected their goal towards the end of their word problem solving. S6 monitored on S5's flawed procedure but was unable to direct him to the correct path. Instead, he was finally persuaded by S5 to accept his flawed procedure. The new procedure, a reallocation of resource, led them away from the goal of the word problem, and as a result, they failed in their word problem solving. This example indicated that the occurrence of metacognitive behaviours on its own does little to ensure successful word problem solving. This concurs with Stillman and Galbraith's (1998) study which revealed that though the successful groups in their study displayed a high number of key points where metacognitive decisions would influence cognitive actions, this alone was not a guarantee of success. They argued that the opportunities for metacognitive decisions to be made did not ensure that they would be made nor if such decisions were made, that they would be appropriate. They suggested that a rich store of knowledge of metacognitive strategies and their facility developed over an extended period of use was a likely prerequisite to productive decision making (Stillman & Galbraith, 1998).

Conclusion

This paper showed the importance of metacognitive training on students' word problem solving in a cognitive-apprenticeship-computer-based environment. The data from the quantitative and qualitative designs point to a need to formulate a specific curriculum

policy to introduce explicit metacognitive training to primary school students to promote metacognitive awareness in the primary mathematics curriculum. Heeding the advice of Stillman and Galbraith (1998), there is also a need to focus metacognitive training which provides facilities that enable students to develop a rich store of metacognitive strategies over an extended period of use.

Acknowledgements

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