Title: Metacognitive Intervention Strategy and Word Problem Solving in a Cognitive-Apprenticeship-Computer-Based Environment

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Abstract: This paper reports on one strand of a larger investigation to examine the extent to which metacognitive training plays a part in primary students' word problem solving in a computer environment. Four 11 to 12-year-olds from a primary school participated in the study which lasted over a period of eight weeks. Students worked collaboratively in a WordMath (Looi & Tan, 1998) environment where a metacognitive intervention strategy was introduced to promote students’ awareness of their cognition. The study adopted a case study design where analysis of two pairs of students’ think aloud protocol data during word problem solving was used to explore the role of metacognition in word problem solving in WordMath environment. Findings of the think aloud protocol data suggested that students had distinctive progressions of word problem solving activity which could be represented by cognitive-metacognitive word problem solving models. These progressions of word problem solving activity seemed to relate to students’ success in word problem solving.

Introduction

There is an emerging consensus that recognises metacognitive skills as essential elements that determine one’s success or failure in problem solving (Schoenfeld, 1992). Research (Cardella-Ellawar, 1995; Oladunni, 1998) employing metacognitive training had also demonstrated that students trained in learning to monitor and control their own cognitive processes for solving mathematics problems do better than untrained students. However, these studies were often carried out in non-computer environments. Attempts had been made to employ metacognitive training within computer environments and its effect examined in mathematics education. These studies (Kramarski & Ritkof, 2002; De Corte et al, 2000) again reported positively about students’ mathematical learning experience after the metacognitive intervention.

Most major studies focusing on metacognition used a quantitative methodology to analyse and draw conclusions on metacognitive components. However, Schoenfeld (1985) and Goos and Galbraith (1996) used qualitative methodology to ‘capture’ and analyse students’ covert metacognitive strategies during problem solving. They used think aloud procedures which gave researchers a glimpse at covert strategy that was not accessible in normal circumstances. Artzt and Armour-Thomas’ (1992) study also used think-aloud protocols to delineate the levels of cognitive behaviours of students’ problem solving in groups. They were apparently successful in identifying the impact of the levels of cognition on groups’ problem solving. All these studies were implemented in non-computer environments, and there remained a research gap that examined students’ cognitive processes in a computer environment.

Singapore’s Masterplan for IT in Education envisages IT being introduced in all subjects, and the use of computers has gradually become a common feature in Singapore mathematics lessons. Though there were some local studies (i.e. Yeap & Kaur, 1998) that tried to identify the role of metacognition in students’ problem solving, there again remained a research gap that examined the effect of providing a metacognitive invention on Singapore primary students’ mathematical word problem solving in a computer environment. This paper reports on one strand of a larger investigation of the effect of metacognitive training on Singapore students’ mathematical word problem solving in a computer environment. Specifically the metacognitive training focused on activating students’ metacognitive processes when solving word problems in a WordMath
environment (Looi & Tan, 1998). The primary aim of the investigation was to identify the role of metacognition and its influence on word problem solving performance in a WordMath environment.

**Methodology**

The study adopted a case study design to explore the role of metacognition in mathematical word problem solving in a computer environment. Four students (11-12 years old) from a Singapore school were involved in the study over a period of eight weeks. The students were chosen based on two factors: having similar academic profiles and being able to work together. These students underwent the following four phases of the study. They included: 1) having four training sessions where the students collaboratively solved word problems in a WordMath environment with a metacognitive intervention strategy called CRIME (Teong, 2003); 2) having two extra training sessions to ensure that the students felt comfortable working collaboratively in front of a video-camera; 3) implementing posttest where students’ think aloud protocols of four word problems were video-recorded and data analysed; and 4) implementing delayed posttest six weeks later, where students’ think aloud protocols of four parallel word problems were again video-recorded and analysed.

CRIME was used as a metacognitive intervention strategy in the study to promote students’ metacognitive awareness. CRIME was an acronym of the word problem solving stages: Careful Reading; Recall Possible Strategies; Implement Possible Strategies; Monitor; and Evaluation. At each stage, questions were used to direct the students to regulate and monitor their word problem solving. In this study, the two pairs of students solved word problems in WordMath with CRIME.

**Analysis and Results**

*Using the modified Artzt and Armour-Thomas framework to analyse protocol data*

A modified Artzt and Armour-Thomas’ framework (1992) was used to analyse the students’ think aloud protocols while solving word problems with WordMath. The original Artzt and Armour-Thomas’ framework (1992) had eleven episodes to partition group think aloud protocols. In this study, the author modified their framework for highlighting major strategic decisions made by the two pairs of students. The behaviours, described in Teong (2003) were: reading (cognitive); analysis (metacognitive); exploration (cognitive or metacognitive); planning (metacognitive); implementation (cognitive or metacognitive); verification (cognitive or metacognitive). The inter-rater reliability coefficient for the coefficient for the four word problems was 0.86. The analysis of students’ think-aloud protocols of the following MARBLE word problem will be used as an illustration of the students’ word problem solving.

*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?*

The overall solution structures of the pairs of students’, S1 and S2, and S3 and S4, word problem solving during post-test and delayed post-test are illustrated in the timeline representations in the following figures, Figures 1, 2, 3 and 4.
Figure 1: S1 and S2’s word problem solving of MARBLE during post-test

Figure 2: S1 and S2’s word problem solving of a parallel MARBLE during delayed post-test

Figure 3: S3 and S4’s word problem solving of MARBLE during post-test

Figure 4: S3 and S4’s word problem solving of a parallel MARBLE during delayed post-test
Data Display Table
A data display table was then tabulated to examine the time devoted to metacognitive and cognitive behaviours when the pairs of students solved the four word problems during post-test and delayed post-test. The data display table for MARBLE word problem is illustrated in Table 1 as shown below.

Table 1
*Time in Seconds (and %) devoted to Cognitive and Metacognitive Behaviours for MARBLE During Post-test and Delayed Post-test*

<table>
<thead>
<tr>
<th>Behaviour Category</th>
<th>S1&amp;S2</th>
<th>S3&amp;S4</th>
<th>S1&amp;S2</th>
<th>S3&amp;S4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metacognitive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td>93 (33.2)</td>
<td>12 (0.9)</td>
<td>148 (36.8)</td>
<td>178 (22.4)</td>
</tr>
<tr>
<td>Explore</td>
<td>0 (0.0)</td>
<td>859 (61.1)</td>
<td>0 (0.0)</td>
<td>182 (22.9)</td>
</tr>
<tr>
<td>Plan</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>15 (3.7)</td>
<td>141 (17.7)</td>
</tr>
<tr>
<td>Implement</td>
<td>88 (31.4)</td>
<td>0 (0.0)</td>
<td>151 (37.6)</td>
<td>132 (16.6)</td>
</tr>
<tr>
<td>Verify</td>
<td>73 (26.1)</td>
<td>107 (7.6)</td>
<td>67 (16.7)</td>
<td>107 (13.5)</td>
</tr>
<tr>
<td><strong>Cognitive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read</td>
<td>26 (9.3)</td>
<td>428 (30.3)</td>
<td>21 (5.2)</td>
<td>55 (6.9)</td>
</tr>
<tr>
<td>Explore</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Implement</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Verify</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

Using modified Artzt and Armour-Thomas cognitive-metacognitive word problem solving model
After drawing the timeline representations to map the flow of the pairs’ cognitive processes in word problem solving against the episodes in the viable framework (see Figures 1, 2, 3 and 4), each pair’s word problem solving behaviour for each of the four word problems was mapped onto the modified Artzt and Armout-Thomas’ (1992) cognitive-metacognitive word problem solving model as shown in Figure 5 below.

![Figure 5: A modified Artzt and Armour-Thomas’ Cognitive-Metacognitive Word Problem Solving Model](image-url)
The purpose of mapping each pair’s word problem solving behaviour onto the model was to examine possible emerging patterns that might arise from the pair’s progression of word problem solving. From the modified cognitive-metacognitive models drawn, there appeared to emerge a unique progression of word problem solving for each pair of students. This emergent progression of students’ word problem solving from the students’ think aloud protocol shed insights to the relationship between the role of metacognition and its influence on the pairs of students’ word problem solving performance. The following figure, Figure 6, represents the students’ overall progression of word problem solving represented as cognitive-metacognitive word problem solving models during post-test and delayed post-test.

<table>
<thead>
<tr>
<th></th>
<th>Post-test</th>
<th>Delayed Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1&amp;S2</td>
<td>6.1</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td></td>
<td>Students were 75% successful in word problem solving</td>
<td>Students were 100% successful in word problem solving</td>
</tr>
<tr>
<td>S3&amp;S4</td>
<td>6.3</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td></td>
<td>Students were unsuccessful in solving all word problems</td>
<td>Students were 50% successful in word problem solving</td>
</tr>
</tbody>
</table>

**Figure 6: A summary of pairs of students’ cognitive-metacognitive word problem solving during post-test and delayed post-test**

**$S1$ and $S2$’s progression of word problem solving**

Figures 6.1 and 6.2, $S1$ and $S2$’s cognitive-metacognitive word problem solving, represent progression of word problem solving that was well-regulated and controlled. The outcome of the students’ word problem solving appeared to be influenced by their ability to be systematic in their progression of word problem solving. With respect to MARBLE, $S1$ and $S2$’s analysis during word problem solving was coherent and they appeared to clarify all their doubts at the beginning of the session before moving on. They were consistently focused, goal driven, well-regulated and explicit in their decision making. These strengths appeared to have contributed to their success in word problem solving. They devoted the highest percentage of time, 33.2% to analysing the word problem, followed by 31.4% and 26.1% of their time to implement (metacognitive) and verify (metacognitive) respectively (see Table 1). They appeared to be satisfied only when they had checked that their solution satisfied the conditions of the word problem.

During delayed posttest, the protocol for $S1$ and $S2$ could also be summarised as a well-regulated progression of activity, Read → Analyse → Implement (metacognitive) → Verify
(metacognitive) (see Figure 6.2), which led to their success in solving all parallel word problems. The control of their word problem solving was evidenced by the percentage of time they devoted to metacognitive activities: analyse (36.8%); plan (3.7%); implement (metacognitive) (37.6%); and verify (metacognitive) (16.7%) (see Table 1).

S3 and S4’s progression of word problem solving

Figure 6.3, S3 and S4’s cognitive-metacognitive word problem solving, represents progression of word problem solving that was dominated by exploration and the students appeared to have difficulties in solving the word problems. With respect to MARBLE, the pair appeared to have limited resources which might have contributed to their failure in their word problem solving. They tried making assessments throughout their word problem solving, but the decisions they made did not help them move away from inappropriate solution paths. They devoted most of their word problem solving to exploration (metacognitive): 61.1% (see Table 1). Not only did they fail in solving MARBLE, but they also failed in solving all word problems during post-test.

In delayed post-test, however, S3 and S4 were successful in solving a parallel MARBLE word problem. The time devoted to exploration (metacognitive) was reduced to 22.9%. They devoted more time to metacognitive activities such as analyse (22.4%), plan (17.7%), implement (16.6%) and verify (13.5%) (see Table 1). Figure 2.4 represents S3 and S4’s progression of word problem solving during delayed post-test. This model is a combination of the progression of word problem solving of S1 and S2’s (see Figures 6.1 and 6.2) cognitive-metacognitive word problem solving and the metacognitive behaviour, exploration. The pair was successful in solving 50% of the word problems in delayed post-test.

Discussion

The findings in this study suggested that students’ word problem solving could be represented by three unique cognitive-metacognitive word problem solving models. These representations of students’ word problem solving seemed to relate to students’ success in word problem solving. Students, whose progression of word problem solving represented by Figures 6.1 and 6.2, appeared to be more successful in word problem solving. The progression of word problem solving was well-regulated and controlled and this usually led to the pairs’ success in word problem solving. These findings concurred with Kramarski & Ritkof’s (2002) and others’ (Cardella-Elawar, 1995; De Corte et al, 2000; Mevarech, 1999) findings where researchers consistently reported that students who were exposed to metacognitive treatment were more aware of their cognitive processes. As a result, this awareness had a positive influence on the students’ mathematical learning experience. In contrast, students, whose progression of word problem solving represented by Figure 6.3, appeared more likely to fail in their word problem solving. Their sequence of activity looked very similar to the pattern of problem solving behaviours of the novice students that Schoenfeld (1985) described in his study, where they engaged in ‘wild goose chases’. However, the analysis of S3 and S4’s word problem solving also suggested that students who had explicit metacognitive training were capable of modifying their progression of word problem solving activity from the one represented by Figure 6.3 to the one represented by Figure 6.4. The progression of word problem solving represented by Figure 6.4 showed some word problem solving features which were similar to the progression of word problem solving represented by Figures 6.1 and 6.2, but the students would also devote time to explore (metacognitive). The ability to modify their progression of word problem solving appeared to contribute to S3 and S4’s improvement in word problem solving performance. This
positive influence might not be demonstrated immediately after the training but there was
evidence that the influence would be delayed.

**Conclusion**
This study constructed some distinctive cognitive-metacognitive word problem solving models,
representatives of the progression of students’ word problem solving, which were related to word
problem solving performance. Though this observation was not conclusive, it was in line with
findings of previous studies as mentioned above that focused on metacognition, and this issue
merited further development.

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