Effects of Cognitive-strategy Intervention on Word Problem-solving Skills of Pre-university Students with Mathematics Difficulties

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***Abstract*—Students who have insufficient word problem-solving skills face difficulty to cope with academic tasks. If no intervention is done, the insufficiency of the skills will hinder their everyday activities at the workplace. The aim of the study is to employ a cognitive-strategy intervention on problem-solving skills of pre-university students with mathematics difficulties given that cognitive-strategy interventions have produced successful outcomes at primary and secondary settings, but little is known about the interventions at post-secondary setting. The domain of mathematics involved is sequence and series, where problems presented in word formats. Single-subject design with phases of baseline, instruction, maintenance, and generalization is employed. The findings suggest that the instructions are to successfully improve students' skills in word problems. Also there is evidence that students are able to maintain their performance few weeks later and generalize reasonably to complex word problems.**

Keywords—mathematics difficulty; cognitive-strategy instuction; word problem-solving; pre-university student

I. Introduction

Given that mathematics plays a crucial role in determining course choices at university and career choices, the academic preparation in pre-university programs is become crucial for many students and institutions. One factor, mathematics difficulties, may hamper readiness of pre-university students to proceed to the next education level. In this study, the terminology, mathematics difficulty, is used instead of mathematics disability. It is simply because no consensus is reached on the classification and definition of mathematics disability [1][3][5].

Mathematics difficulty has been exclusively, but not exhaustively, investigated at primary and secondary educations. And its prevalence has been widely reported. Students with mathematics difficulties reached a plateau after 7th grade in their mathematics ability and progressed 1 year's growth during grades 7 through 12 [2]. The converging evidence suggested that 5 to 8% of school-age children exhibit some forms of deficits in arithmetical competencies [3]. In addition, the top ranked challenges faced by students with mathematics difficulties in grades 8 through 12 were [4]: (1) had difficulty with word problems, (2) had difficulty with multi-step problems, (3) had difficulty with the language in mathematics, (4) failed to verify answers and settled for first answer, (5) unable to perform simple calculations, and (6) took a long time to complete calculations.

The learning difficulty is suspected to relate to working memory deficit [5]. Students with working memory deficit may face difficulty in solving multi-step problems as the problems involving many steps to work on and are required students to stay alert on any chance of making any errors in the solution progress. A recent synthesis review found that working memory as a main factor that differentiating average-achieving students from those with mathematics difficulties [6]. Another possible deficit was visual-spatial in which students with mathematics difficulties face problems to write an equation on a straight line or on a small space and have difficulties in pictorial or diagram representation [16].

On intervention to remediate mathematics difficulties, cognitive-strategy instruction is a promising approach [7][8][13][14]. It was shown to be an effective instructional intervention to enhance students' mathematical skills particularly problem-solving. Problem-solving is a skill to be learnt and mastered by students that is embedded in word problems across many topics in mathematics [15]. Cognitive-strategy instruction is based on both behavioral and cognitive theory [9]. Direct instructions (e.g., verbalization, modeling, practice, feedback) are used as a tool to guide students in the mastery of cognitive strategies with embedded self-regulation activities (e.g., self-instruction, self-evaluation). Moreover, the combination of direct instructions and strategy instructions models is effective in remediating mathematics learning difficulties, which is clearly evident in the literature on instructional interventions [10].

A. Present Study

However, vast majority of interventional studies have primarily focused on primary and secondary students on task domains ranging from mathematics fact retrieval to problem solving in algebra, which involved tasks of one or two steps. Given that a wide range of mathematical domains, more work needed to be done. For this study, the task domain is pertinent to sequence and series, which is a prior knowledge for learning more complex mathematical tasks related to business mathematics. Additionally, in sequence and series, students need to use their algebraic skills flexibly. Specifically, the cognitive-strategy intervention focuses on training pre-university students with mathematics difficulties to solve word problems of geometric sequence. It is hypothesized that the learning and the use of strategy will improve students' word problem-solving skills in that mathematical domain.

II. METHODOLOGY

A. Participants

The participants were 3 pre-university students in a program at a private college. They were: Alan (male, 18 years old), Cindy (female, 18 years old), and Nick (male, 19 years old). Criteria for inclusion were: (1) poor mathematics performance, which is not due to poor class instructions, (2) had average or good command of English, (3) good class attendance, and (4) all were recommended by their teachers.

B. Setting

All activities and/or instructions were handed by the instructor with many years of teaching experience. All were done on one-on-one basis in a consultation room with quite environment.

C. Dependent Variable

One dependent variable is defined as score for 5 questions for probe tests. All probes consisted of word/story problems of geometric sequence and were designed by the researcher. A total of 10 points for each probe test with 1 point is awarded for the correct mathematical sentence (or equation) and 1 point for the correct answer. For probes at generalization phase, the same number of questions with the context, which is from Financial Mathematics. For all probes, students are allowed to use calculator for all probe tests.

D. Experimental Design

A design of multiple-probe-across subjects was used with phases of baseline and instruction, and generalization and maintenance [11]. The advantage of this type of experimental design is it allows an experimenter to change the course of instructions from time to time.

E. Baseline

During this phase, no explicit instruction was introduced to solve word problems. Each student was administrated a probe test for each session. And students took approximately 30 minutes to complete probe tests. Students were encouraged to use any approach to solve word problems. The instructor observed and recorded the approach used by the students.

F. Intervention

The intervention strategy was adapted from reference [8]. The duration for all sessions was ranged from 30 minutes to 45 minutes. The intervention phase included:

1) Activation of prerequisite knowledge: It was mainly on algebra.

2) Discussion on their performance and importance of strategy use: The main idea was to create awareness the importance of strategy use. Students were encouraged to strike to their best during all sessions of instructions.

3) Discussion of the five-step strategy of problem solving:

a) *read the problem loudly.*

b) *look for key words and circle them.*

c) *use of diagrams to unlock the problem.*

d) *write down the mathematics sentence.*

e) *write down the answer.*

4) The self-regulated activities: self-instruction (e.g., "Five-step strategy would help me to solve the problem"), self-recording (e.g., students keep the records of sessions and put remarks), and self-evaluation (e.g., "Does the answer make sense in this problem").

5) Modeling of the strategy and self-instructions through think aloud: Demonstration of the strategy by the instructor while students observe how a word problem to be solved. Think aloud is referred to a person says it out while thinking.

6) Mastery of the strategy: Students needed to repeat the five-step strategy until they could successfully use this strategy during practice. Performance must achieved at least 80%.

7) Guided practice of the strategy and self-instructions: Students were guided by the instructor and cues were provided for unsuccessful strategy use. They may refer to the five-step strategy and self-instructions printed in papers.

8) Independent practice/performance: For this stage, students could use the strategy and sel-regulated activities fluently without cues from the instructor and/or reference to their notes.

G. Materials

Five steps of the strategy were printed in an A4 paper and three self-regulated activities printed in another A4 paper. A performance sheet was used to record their academic progress.

H. Procedures and Data Collection

One subject was administered probes until stability of mathematics performance was observed (in baseline phase). This was followed by the introduction of instructions until mastery of the strategy was achieved. It then continued with probes (in instruction phase). Once the stability of performance was achieved, another subject entered the baseline and repeated the same process as the previous subject. For each subject, performance was measured during generalization and maintenance, which was 2 weeks after the last probe in the instruction phase.

I. Inter-rater Agreement

One experienced mathematics instructor from the same pre-university program helped to score approximately 20% of probe tests across students. Inter-rater agreement ranged from 89 to 100% for the first participant. The measure for the second participant ranged from 90 to 98%. The range was from 93 to 100% for the third participant.

III. Results

The analysis involves the report of description of students' performance on word problems as well as their trend of performance. These are the common features for visual analysis of single-subject designs [11]. Figure 1 shows performance of students at different phases, baseline and intervention, and also during maintenance and generalization of the strategy.

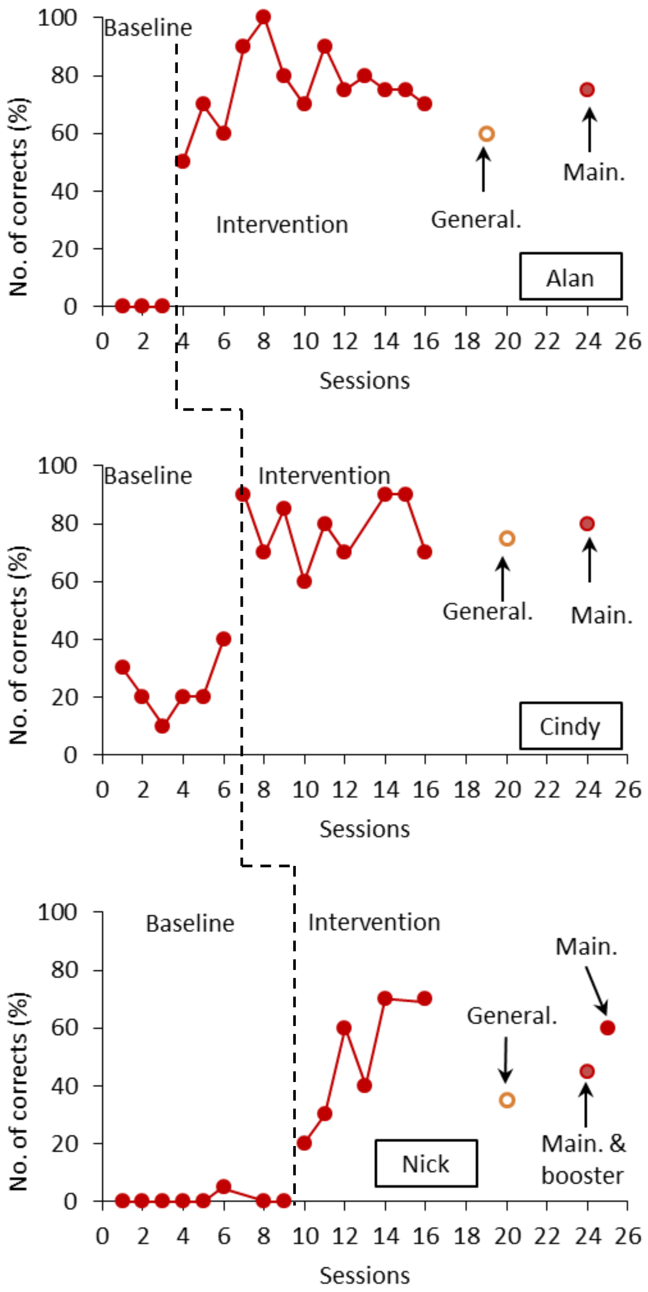

Fig. 1. Number of correct answers over sessions for three students.

A. *First Participant (Alan)*

At the baseline phase, his performance in word problems of geometric sequence was ranging from 0 to 0% with a mean of 0%. Upon the institution of instructions, improvement in performance was immediately observed. Score went up to the maximum level but it was declined at the end. The score was ranging from 50 to 100% with a mean of 75.77%. Generalization of the strategy to another topic, which was Financial Mathematics, was evident with its score was about 60%. He was able to maintain performance (reached 75%) 2 weeks after the last probe.

B. *Second Participant (Cindy)*

Initial performance was rather poor but it was better than the other two subjects, and score was ranging from 10 to 40% with a mean of 23.33%. After the intervention, performance immediately improved to the excellent level (reached 90%). Score was ranging from 60 to 90% with a mean of 78.33%. Her scores of probes were quite stabilized during the intervention phase. She was able to generalize the strategy to word problems of Financial Mathematics (reached about 75%). Performance was able to maintain (reached about 80%) 2 weeks after the last probe.

C. *Third Participant (Nick)*

Geometric performance was very poor during the baseline, and probe score was ranging from 0 to 5% with a mean of 0.62%. After the intervention, his performance was climbed slowly from session to session and reached an above-average level (about 70%) at the end of intervention phase. Overall, score was ranging from 20 to 70% with a mean of 48.33%. Generalization of the strategy to another topic was poor (reached about 30%). His score at maintenance phase dropped below the level of last few probes to only 40%. And the five-step strategy was immediately reintroduced to the student. His score was improved to about 60% in the subsequent session.

IV. Discussion

The purpose of the study was to examine the effectiveness of the five-strategy intervention and metacognitive activities on mathematical problem-solving skills of pre-university students with mathematics difficulties. The results were encouraging given that 2 out of 3 students were able to achieve a mastery level and to maintain the mastery level two weeks after their last probe. And one of them was able to achieve the full score for one of the probe tests. The most interesting finding was that 2 out of 3 students were able to generalize the five-step strategy and self-regulated instructions from word problems pertinent to geometric sequence to complex word problems in business mathematics. It was an important piece of evidence as what was learnt in one familiar context could be applied in a strange context. However, the discouraging evidence was one student did not respond to the intervention well as compared to the other two students and the generalization of the strategy was also poor. For this student, it reserves a further investigation on factors that may delay responsiveness to instructions.

The findings from this study were consistent with findings of previous research, both in single-subject design and group design studies, where the cognitive-strategy interventions were employed [7][8][12][13][14]. The before-mentioned studies mainly focused on secondary students with mathematics difficulties, and mathematical domains were exclusively focused on algebra. These previous studies attempted to foster problem-solving skills in general contexts, which were suitable for secondary students' level of understanding in mathematics. While, in this study, pre-university students were much matured than those of the previous studies but had the same learning difficulty. And also, the mathematical context for this study was more complicated than those studies in the past. Although differences are observed in terms of student maturity and mathematical domains, the outcome of this kind of interventions is the same. It has a positive causal effect on students' problem-solving skills. The result signifies that this type of interventions could be applied on older students with mathematics difficulties and more complex mathematical tasks. It is something new to be added into the literature of cognitive-strategies interventions.

The intervention of this study utilized explicit and direct instruction (e.g., modeling, practice, feedback) to guide the learning of the five-step instructional sequence and activities of self-regulation. The direct instructions, the five-step strategy and metacognitive activities were used as a package to achieve the total effect on students' ability to solve word problems. The overall effect of the package of instructions was very similar to the instructions directed by teachers in classrooms. Such strategy could be used by teachers at pre-university level to work closely with students with mathematics difficulties to overcome some obstacle while solving word problems as it is the top challenge faced by many students [4].

V. LIMITATIONS

There are several limitations. First, the study involves pre-university students at a private college. It is therefore the findings should be used with caution when the intervention to be used at public institutions. Second, single-subject design is employed and instructions are delivered on one-on-one basis. The findings may not be applied when the same instructions are applied for a large group of students in classroom. Third, the mathematical domain in this study involves sequence and series, so the findings may not be well generalized to other domains given that mathematics covers a wide range of topics. Fourth, the relative contribution among different instructional components to word problem-solving skills could not be justified. This limitation is reserved attention as many instructors look for the most effective instructions.

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