Learning and Problem Solving Strategies of ESL Students

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Abstract

The mathematics problem solving approaches of a group of elementary and secondary ESL students were investigated through a performance assessment accompanied by think-aloud procedures. Students were enrolled in ESL mathematics classes in a Title VII project implementing the Cognitive Academic Learning Approach (CALLA). In this approach, curriculum content is used to develop academic language and learning strategies are taught explicitly to increase students metacognitive awareness and to facilitate their learning of both content and language. Participating teachers were identified either as high implementation teachers (extensive involvement in staff development and other project activities) or low implementation teachers (limited involvement in project activities). The study was designed to identify learning and problem solving strategies of students at high, average and low mathematics achievement levels, and to compare strategic approaches of students in high implementation and low implementation classrooms. The results indicated that significantly more students in high implementation classrooms were able to solve the problem correctly than were students in low implementation classrooms. As expected, students rated high in math performance also performed significantly better on finding the correct problem solution. Of greater interest was the finding that there were no differences in the actual number of problem solving steps used by students in the two implementation levels, but that significant differences for high implementation classrooms were found for correct sequence of problem solving steps, which has been featured in instruction in the high implementation classrooms. This seemed to indicate that explicit instruction in a problem solving sequential procedure is helpful for ESL students. In addition, students in high implementation classrooms used significantly more metacognitive strategies than students in low implementation classrooms. High math ability students used the most metacognitive strategies in all types of classrooms. with average math ability students using fewer metacognitive strategies and low math ability students using the fewest metacognitive strategies. This finding seemed to indicate that students who were the highest achievers in mathematics and who received information about and practice in metacognitive strategies (such as planning, monitoring, and evaluating one's own learning) were better able to regulate their learning than less able math students or students in low implementation classrooms. Problems identified in the study were that even in high implementation classrooms, lower achieving students did not use the correct sequence of problem solving steps. Reasons could be attributed to differences in mathematics ability, differences in linguistic competence (since the task involved reading and understand a word problem), and/or amount of prior knowledge about learning and problem solving strategies. More research is needed to clarify these and other problems related to mathematics achievement of ESL students.

Introduction

Students learning English as a new language face many challenges in American schools. Not only must they learn a new system of communication and become comfortable with a new culture, but they must also use the new language to learn the academic subjects of the curriculum. Investigations in both Canada and the United States have shown that while students speaking a language other than English at home can learn enough English for social communication in about two years, they need from five to seven years or more to adequately develop the language skills needed in academic subject areas (Collier, 1987; 1989; Cummins, 1984). One proposed solution to shortening this lengthy period of academic language learning is to provide content instruction through students' native language so that they do not lose ground conceptually while they are acquiring English. Another solution is to restructure the English as a second language (ESL) program by including in it essential content drawn from the school's grade-level academic program.

This study describes the mathematics problem solving approaches of a group of students served by a Title VII Special Alternative Instructional Program designed to provide integrated mathematics and language instruction to beginning and intermediate level ESL students. The instructional model being implemented in this project is the Cognitive Academic Language Learning Approach (CALLA) applied to mathematics. CALLA is designed to provide instructional experiences in English that will prepare ESL students for greater success in grade-level classrooms. CALLA is based on a cognitive model of learning and integrates high priority content from the grade-level curriculum, a focus on academic language development through content, and explicit and overt instruction in learning strategies (Chamot & O'Malley, 1987, 1989, 1993; O'malley and Chamot, 1990).

In cognitive theory, learners are viewed as active mental processors of information and skills. Cognitive theory is reflected in current views about teaching and learning, including schema-based reading theories and process-writing approaches. The CALLA model incorporates cognitive theory and instructional practice applied to content-ESL classrooms in which students are learning both language and content.

Background

Instructional approaches based on cognitive learning theory have been described for major areas of the curriculum, including reading, writing, mathematics, and second languages (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Chamot & O’Malley, 1993; Gaskins & Elliot, 1991; Jones, Palincsar, Ogle, & Carr, 1987; O’Malley & Chamot, 1990). Such approaches have in common an understanding that learners construct knowledge by making connections between their prior knowledge and new information, and analyze new learning activities to determine the most effective approach to achieve learning goals. Cognitive instruction seeks to facilitate learning by making students aware of their own mental processes and by providing direct instruction in thinking and learning strategies (Jones & Idol, 1990).

Learning strategies are the purposeful actions and thoughts learners engage in for understanding, storing, and remembering new information and skills (Weinstein & Mayer, 1986). Some learning strategies are observable, as in note-taking or writing a plan for problem solution. Many learning strategies, however, are non-observable because they are purely mental processes. Examples of non-observable strategies are monitoring comprehension or activating prior knowledge. Since learning strategies can be used with any learning task, including mathematics and language tasks, they have considerable potential for enhancing the academic achievement of linguistic minority students. Research in both first and second language contexts indicates that effective learners use appropriate learning strategies when they work on academic tasks, whereas less effective learners apply strategies infrequently or inappropriately (Chamot & Küpper, 1989; Derry, 1990; Gagné, 1985; O'Malley & Chamot, 1990; Wenden & Rubin, 1987).

Three types of learning strategies are commonly discussed in the literature: *metacognitive strategies,* or the executive strategies that individuals use to plan for, monitor, or evaluate learning; cognitive strategies, the actual manipulation of learning materials by re-organization and grouping, elaboration or relating one new idea to another and relating new ideas to existing knowledge; and social-*affective strategies,* in which the learner calls on another person for assistance or works cooperatively with others on a common task.

Considerable success in teaching less effective students to apply useful learning strategies has been reported for first language students in several curriculum areas (Pressley & Harris, 1990). Instruction in various reading strategies, for example, has significantly improved the reading comprehension of poor readers in a number of studies (Gagné, 1985; Garner, 1987; Palincsar & Brown, 1984; Pressley & Associates, 1990). Similarly in mathematics, instruction in problem solving strategies has had a positive effect on student achievement (Peterson, Fennema, & Carpenter, 1989; Pressley & Associates, 1990; Silver & Marshall, 1990). Although limited research on learning strategy instruction in second language contexts has been conducted, success has been reported in teaching students to apply learning strategies on second language tasks (Hosenfeld, Arnold, Kirchofer, Laciura, & Wilson, 1981; O'Malley, Chamot, Stewner-Manzanares, Russo, & Küpper, 1985; Politzer & McGroarty, 1985).

In mathematics, principles of cognitive instruction are embodied in the curriculum standards developed by the National Council of Teachers of Mathematics (NCTM). These standards state that major objectives for mathematics instruction are problem solving, reasoning, and communicating mathematically (NCTM, 1989, 1991). Through studying mathematics, students should be able to solve problems encountered in the real world and to reason and talk about their solutions. In this approach to mathematics instruction, language plays a much larger role than has been the case in traditional computation-based programs. For example, students need good comprehension skills (both oral and reading) in order to understand a problem, and they also need good speaking skills in order to discuss the problem and explain their path to solution. Writing skills are also needed in mathematics if students are to write about their problem solutions (Dossey, 1989). In addition to language skills, mathematics problem solving also requires a strategic approach to understanding and representing the problem, and making and carrying out a plan for its solution. The strategic approach generally recommended for mathematics problem solving is based on Polya’s model, which consists of understanding the problem, devising a plan, carrying out the plan, and looking back (Polya, 1957, 1973). Teaching students appropriate strategies for working through each of these steps of the problem solving process has improved performance at all grade levels, including college students (Silver & Marshall, 1990). Thus, effective problem solvers appear to use specific problem solving steps that lead to success in mathematics. Nevertheless, empirical evidence of the impact of individual strategies within the Polya model is lacking (Pressley & Associates, 1990). What is important is that following the problem solving steps of the Polya model in *sequence* is a highly effective approach to solving word problems (Pressley & Associates, 1990). Specific learning strategies appropriate for each step of the model have been identified by a number of researchers, and include elaboration of prior knowledge, selective attention or focusing on important information, evaluating the plan, and representing the problem pictorially (Chamot & O’Malley, 1993; Dirkes, 1985; Pressley & Associates, 1990). Cooperation, or solving problems in small groups, is another strategy that has a positive effect on problem solving and on helping students develop metacognitive awareness of their own mathematical thinking (Hyde & Bizar, 1989; Noddings, Gilbert-MacMillan, & Leitz, 1983; Slavin & Madden, 1989). Benefits of solving problems cooperatively include sharing strategies, communicating mathematically, and developing skills needed for independent learning.

In addition to following specific problem solving steps, effective problem solvers maintain a reflective view of their own problem solving processes. They analyze related information, look for possible solutions, and check the accuracy of alternative solutions (Dirkes, 1985). Such metacognitive knowledge and executive control over problem solving provides the student with flexible and autonomous control over the learning process. In addition to metacognitive control, an effective problem solver will brainstorm a variety of alternative plans or solution strategies, activate what has already been learned, try the plan out with the current problem, and evaluate its application to the solution (Dirkes, 1985). The student's evaluation of the plan must be performed with respect to the original problem representation rather than to the simple computational procedures used to find the answer (Noddings, Gilbert-MacMillan, &Leitz, 1983).

While mathematics programs in schools are beginning to change in response to the NCTM standards and to research on cognitive instruction in mathematics (Peterson, Fennema, & Carpenter, 1989; Silver & Marshall, 1990), mathematics instruction for students learning ESL is frequently limited to computation exercises and little or no time is spent in problem solving (Secada, 1991). Promising programs do exist, however, which are being driven by the growing national interest in the integration of language and content instruction (see Spanos 1990 for a review and annotated bibliography). ESL math classes have been developed at schools such as the International High School in New York and in several school districts around the country (see Santiago & Spanos, 1993, for a description of the program at the International High School as well as a listing of resources and contact organizations). If ESL students are to achieve success in mathematics classes they need to develop problem solving, reasoning, and mathematics communication skills.

Purpose of the Study

The purpose of this study was to investigate the effects of cognitive instruction in mathematics on the approach to problem solving of ESL students. The specific objectives of the study were to: (1) identify the learning and problem-solving strategies used by ESL students in solving a mathematics word problem; (2) compare the problem-solving approach of students whose teachers participated in a cognitive instructional program with students whose teachers did not participate or participated to a lesser extent in the program; and (3) describe differences in strategy use of students at different levels of mathematics achievement. Students in high implementation classrooms were predicted to make more use of learning strategies and more use of mathematics problem solving steps than students in low implementation classrooms. Also, students nominated as higher in math ability were predicted to use mathematics problems solving steps more than students rated lower in mathematic ability.

Setting. The study took place in a small urban school district of approximately 15,500 students, of which about thirty-four percent are from language minority backgrounds. About sixteen percent of the students in the district have been identified as limited in English proficiency. Although more than 52 different languages are represented in the language minority population, sixty-nine percent of students with limited English proficiency are Spanish speaking. An intensive ESL program is offered at all middle and high schools and at elementary schools with large numbers of students learning English. In recent years the ESL program has moved from being primarily language-based to content-based, and now offers, in addition to language arts, science, mathematics, and social studies for ESL students. CALLA is used for both ESL mathematics and ESL science.

The 1991-1992 evaluation of the CALLA Mathematics project found that students in the program made substantial gains in standardized achievement test score in computation (an average of 7 NCEs) and even greater gains in concepts and application (an average of 10 NCEs). The program achievements were summarized by the evaluator as follows (Thomas, 1992):

> Finally, the evaluations of the CALLA program for the past three years have demonstrated clearly that the CALLA instructional approach represents one of several possible powerful approaches to increasing the achievement of limited-English-proficient (LEP) students in the long term so that they may receive maximum benefit from their schooling. The evaluator recommends that the Arlington school staff closely examine the CALLA instructional strategies and methods, and seek to incorporate the best of these into an already successful language minority student instructional program. There is substantial evidence that this program results in dramatic and sustained achievement gains for language minority students. As such, Arlington educators are encouraged to add it to their instructional program as a

> full-fledged part of the effort to improve the educational opportunities for language minority children. CALLA represents a set of now-proven instructional strategies from which all students can benefit and by means of which successful programs can be made even more successful. (p. 6)

Staff development activities for the CALLA Mathematics project have emphasized the importance of providing direct instruction in learning strategies and teaching problem solving procedures. Learning strategies emphasized were metacognitive strategies such as planning and self-evaluation, cognitive strategies such as elaboration of prior knowledge, and social/affective strategies such as cooperation. Table 1 lists the learning strategies taught and their definitions.

Specific techniques for teaching problem solving include modeling a problem solving procedure, explaining a problem solving procedure to students, having them work in cooperative groups to follow the steps to problem solution, and asking them to explain orally or in writing how the solution was achieved. The following five-step problem solving sequence, based on Polya (1957; 1973), was featured in teacher workshops and methods courses:

1. **Understand the Question**. Activities include reading the problem aloud, discussing prior knowledge about the problem type, drawing a picture or image of the problem, rewriting the question as a statement with a blank for the answer, paraphrasing the question.

2. **Find the Needed Data.** Activities include underlining or circling data needed, crossing out extraneous information, and comparing circled numbers to the pictorial representation developed in 1.

3. **Make a Plan.** Activities include deciding if one step or multiple steps are called for, choosing the operation(s), making a table or other graphic representation, guessing and checking, writing a number sentence, or otherwise setting up the problem.

Table 1
Learning and Problem-Solving Strategies
Taught in CALLA Math Project

Metacognitive Knowledge and Strategies: Understanding own learning processes and task demands. Regulating own learning through planning, monitoring and evaluating activities	
Problem	Explicitly identifying the central question that needs
Selective Attention	Planning to attend to specific aspects of the word problem that will assist in its solution. Example:Identifying information needed to solve the problem (and eliminating unnecessary information)
Organizational Planning	Generating a plan and proposing strategies for the parts and sequence to solve the problem.
Self-Monitoring	Checking on the progress of solving the problem - catching mistakes as they happen.
Self-Evaluation	Judging how well the task has been accomplished and how successfully the problem has been solved.
Self-Management	Knowing the conditions that assist one to learn and arranging for those conditions.
Cognitive Strategies: Interacting with the material to be learned by manipulating it mentally or physically.	
Grouping	Classifying concepts according to their attributes.Example: Making a table or an organized list of information in a problem.
Elaboration	Relating new information to prior knowledge and experiences.
Inferencing/ Predicting	Using context to guess new words and using information from the problem to predict solution.
Note-taking	Writing down needed information in abbreviated verbal,numeric, or graphic form
Deduction	Applying rules to solve problems.
Imagery	Using mental or real pictures to understand or solve a problem.
Social Affective Strategies: Interacting with other persons or using affective control to assist learning.	
Questioning for Clarification	Getting additional explanation or verification from a teacher or other expert, or posing questions to one's self.
Cooperation	Working with peers to understand and solve a problem
Self-talk	Reducing anxiety through positive self-direction.

4. **Solve the Problem.** Activities include working with pencil and/or calculator to compute the answer to the problem(s) set up in 3.

5. **Check Back.** Activities include comparing the answer to the representation made in 1 to see if it makes sense, reviewing the problem solving steps, looking for more information in the problem, estimating the answer, checking calculations.

Teachers were encouraged to make posters of the five problem solving steps to use as visual aids to assist students in approaching word problems in a systematic fashion. Some teachers made separate posters for each step which had specific directions for completing that step. An expanded version of the five-step problem solving procedure was developed by Spanos for use in his high school ESL math class (Arlington Public Schools, 1991). This Word Problem Procedure (WPP) provides specific directions for each of the five problem solving steps and includes additional instructions designed to assist students in dealing with the linguistic demands of the problem (see Appendix A). The WPP steps include, in addition to the five-step problem solving procedure taught by other high implementation teachers, planning and evaluation steps which involve metacognitive learning strategies.

Methods

The data collection methods employed in this study were think-aloud interviews in which students were prompted to describe their thoughts as they attempted to solve a mathematics word problem. The think-aloud protocol was followed immediately by a retrospective interview in which the student was asked questions about his or her approach to solving the problem. All interviews were tape-recorded and student worksheets were collected.

Subjects. The subjects were 32 low or intermediate English proficiency level students in elementary, middle school, and high school ESL-Mathematics classrooms. Twenty-five students were Hispanic, and the remaining seven were from a variety of other language backgrounds, as shown in Table 2. Most (24) had no deficits in the number of years of schooling, but eight had a deficit of one to five years of schooling. Students' length of residence in the United States ranged from one year or less to more than three years. All students had been receiving CALLA instruction in mathematics for the full school year.

Table 2
Student Background Information

Language		**Previous Schooling**	
Spanish:	25	Normal schooling:	24 at grade level
Hindi:	1	1 year:	2
Urdu:	1	2 years:	1
Russian:	1	3 years:	3
Vietnamese:	3	4 years:	1
Korean:	1	5 years:	1
Time in U.S.		**School Level**	
1 year or less:	4	Elementary:	9
1-2 years:	16	Middle:	13
2-3 years:	11	High School:	10
3+ years:	1		
Math	**Level**	**Number of Students who correctly solved problem: 7 (all H)**	
L	11	2 from L implementation teachers	
A	8	5 from H implementation teachers	
H	13		

Instruments. An interview guide was developed to detect uses of problem solving strategies taught in classrooms, piloted with a sample of students and revised. The final interview guide (Appendix B) used for think-aloud and retrospective interviews consisted of four parts: (1) Warm-up - Background Questions; (2) Think-Aloud Warm-up; (3) Word Problem Think-Aloud; and (4) Learning Strategy Discussion (Retrospective Interview).

The Think-Aloud Warm-up consisted of two 2-digit computation problems (1 addition and 1 multiplication) and was used as a training device to have students practice thinking aloud.

Two math problems were presented for the Word Problem Think-Aloud, the first more difficult than the second. The second problem was included to serve as an alternate in case students experienced frustration with the first problem. Selection of the word problem was based on the following criteria: (1) to be somewhat difficult for most students; (2) to include extra or unneeded information; (3) to enable problem solution without understanding every word (although some words were key to solving the problem); and (4) to ask more than one question. Thus, a challenging problem was deliberately chosen to elicit as wide a range as possible of learning and problem-solving strategies.

The retrospective learning strategies discussion consisted of questions about how the student had tried to solve the problem. For example, students were asked: “Did you make a plan before you started working on the problem?” If the answer was affirmative, the student was asked to describe the plan. Similarly, students were asked: “Did you make a picture in your mind to help you understand the problem?” If the student said yes, he or she was asked to describe the mental picture.

Procedures. The level of participation in staff development and other project activities has varied from teacher to teacher, and the degree of implementation in classrooms of strategic approaches to problem solving has varied as well. Teachers were classified as high (H) CALLA implementation or low (L) CALLA implementation based on the following criteria: (1) graduate credits earned in CALLA methods courses; (2) participation in staff development activities; (3) participation in CALLA math curriculum development; (4) responses on questionnaire about learning and problem-solving strategies taught directly and indirectly, and amount of time spent per week on word problems (Appendix C); (5) classroom observation of problem solving activities; and (6) evidence of expertise in teaching CALLA math (e.g., nomination as instructional coach, years of active participation in program). Points were awarded for each criterion met. The points were based on a combination of actual hours devoted to the activity and level of effort required by the activity. Table 3 summarizes instructional implementation information and indicates the number of teachers earning points for each criterion.

On the basis of the above criteria, eight teachers were classified as high (H) implementation, while seven were classified as low (L) implementation. Scores ranged from a high of 86% of possible points to a low of 15% of possible points. Teachers receiving a score of 54% or higher of possible points were identified as high implementation teachers, with the group of low implementation teachers identified as scoring 49% or lower of possible points.

Table 3
Level of Teacher Participation in CALLA Program

Activity	Description	Points Awarded	Teachers Receiving Points
Summer curriculum writing	Development/revision of CALLA math curriculum	2	5
CALLA 2 credit course	Graduate level course on CALLA methods	4	5
CALLA 1 credit course	Graduate level course on program implementation	2	4
Workshops	3 hr. hands-on workshops (conducted during school hours)	1-3	15
Technical Team meetings	Monthly planning; test, curriculum, materials development (after school)	1-2 per year	9
Program experience	Years in program combined with graduate course and/or curriculum writing	1-2	8
Instructional coach	Nominated to coach new teachers	3	5
Classroom observation	Teacher observed teaching problem solving	2	8
Questionnaire	(see App. C)		
Learning strategies taught directly	Number of strategies checked under **Direct**	2 each (14 poss.)	15
Learning strategies taught indirectly	Number of strategies checked under **Indirect**	1 each (7 poss.)	11
Problem solving strategies taught	Number of problem solving strategies taught	1 each (13 poss.)	15
Frequency of problem solving instruction	Frequency checked (from *once a week to every day*)	1 each (5 poss.)	15

All 21 ESL math teachers were informed of this study and were asked for their voluntary participation. The 15 who agreed to participate were asked to select two students in each of the following categories: a high (H), average (A), or low (L) in math performance level (as students had already been assigned to classes based on their English proficiency level). Criteria for selection included mathematics test scores and current classroom performance. Teachers were also informed that participating students would be taken out of the class individually and asked to solve a word problem, “thinking aloud” as they did so. Immediately following the word problem, they would be asked some additional questions about their use of learning and problem-solving strategies. Generally, the interviews were 15 minutes or less in duration. The interviews were conducted by three different interviewers and took place during late spring of the school year. By this time, it was expected that students should have had sufficient instruction in learning and problem-solving strategies to be able to use them in solving problems, at least in high implementation classrooms. All the interviews were conducted in English, except for five which were conducted in Spanish when it became apparent that the student could not respond in English. Interviews conducted in Spanish were translated to English prior to analysis.

Analysis

The think-aloud portion of the interviews was transcribed verbatim. Unclear portions were reviewed by the interviewer of that student, and in most cases it was possible to identify the ambiguous word or phrase used by the student. Student answers to each question on the retrospective interviews were summarized in abbreviated form.

A training session was conducted on coding the verbatim transcripts for evidence of strategic behavior using materials developed for think-aloud coding in previous studies (e.g., Chamot & Küpper, 1989; O’Malley, Chamot, & Küpper, 1989). The three interviewers then coded a sample of transcripts independently, writing down names of strategies as they occurred in the transcripts. They met again to compare the results and to resolve any differences. When agreement could not be reached on a particular item, it was left uncoded. This process continued until all 32 transcripts were satisfactorily coded for evidence of learning strategy use.

A second coding was undertaken subsequently for the purpose of identifying the occurrence of the problem solving steps that had been taught in high implementation classrooms. All transcripts were coded independently for problem solving steps by two raters. Their initial agreement level on a sample of 10 students selected from high and low categories for student math ability and teacher-implementation was at least 85% for the five problem solving steps.

The two raters then met to resolve differences in the same manner as had been used for the learning strategy coding described above. The dependent variables included in this study were all obtained from transcripts of the taped "think aloud" interviews and were as follows:

1. **Problem Score** -- scored 1 if the student got the "think aloud" problem correct and 0 if it was incorrect;

2. **Total Number of Problem Solving Steps** -- the total number out of the five problem solving steps that were identified from the transcript of the student's interview;

3. **Sequence of Problem Solving Steps** -- the appearance of at least three of the five problem solving steps in the correct sequence in which they were taught, e.g., the sequence ACD would receive a score of 3 and ABCDE would be scored 5, but ACE would receive 0 points;

4. **Metacognitive Strategies** -- the number of metacognitive strategies in the interview, viz., selective attention, planning, monitoring, self-evaluation, self-management, or metacognitive knowledge of the task; and

5. **Cognitive Strategies** -- the number of cognitive strategies in the interview, viz., grouping, note-taking, imagery, elaboration, or inferencing.

Mean scores and standard deviations were computed for students with different levels of mathematics ability (high, medium, and low) who were taught in classes differing in level of implementation (high, low). A two-factor analysis of variance was performed using each of the dependent variables. The first factor was teacher level of implementation of the CALLA program (high, low), as defined above, and the second was student level of mathematics ability (high, average, low), as rated by the teacher.

Results

Mean scores and standard deviations for the dependent variables differentiated by level of implementation and level of student math ability are presented in Table 4. Generally, the students were evenly distributed among the cells in the analysis. However, there was one cell in the analysis of variance that was represented by a single case, a low implementation classroom with students of average ability. At a later time, we plan to use a regression analysis to confirm the differences found in the analysis of variance to be reported below.

Results of the analysis of variance in Table 5 indicated that significantly more students in high implementation classrooms scored correctly on the problem compared to those in low implementation classrooms. Also, students rated as high in problem solving ability got the problem right significantly more often than those rated average or low in ability. In fact, none of the students rated average or low solved the problem correctly. A post-hoc analysis of differences in length of residence in the United States among the groups did not reveal any meaningful differences that appeared to coincide with these or the other findings presented below.

There were no differences in total number of problem solving steps between students in classrooms at the two different levels of implementation. However, significant differences were found in the total number of problem solving steps mentioned correctly among students at the different levels of math ability. The order of the means was in the predicted direction, with high ability students mentioning more steps than students in the average groups, who mentioned more steps than students in the low ability groups. The fact that one student rated average in ability in the low implementation group mentioned all five problem solving steps did not produce a significant interaction term.

Although level of implementation did not appear to produce differences in the total number of problem solving steps mentioned by students, implementation had a significant influence on the sequence in which the problem solving steps were mentioned. Students in higher implementation classrooms produced responses with the correct sequence of problem solving steps more often than students in low implementation classrooms. In addition, there were significant differences between students at the different ability levels. The order of means was as would be expected, with high

Table 4
Means and Standard Deviations for Selected Student Variables by Level of Teacher Implementation and Level of Student Math Ability

		Level of Implementation					
		High			Low		
Variable	Student Math Ability	n	Mean	SD	n	Mean	SD
Problem Score	High	6	0.83	0.41	7	0.29	0.49
	Average	7	0.00	0.00	1	0.00	0.00
	Low	6	0.00	0.00	5	0.00	0.00
	Total	19	0.26	0.45	13	0.15	0.38
Total No. Problem Solving Steps	High	6	4.17	0.75	7	3.71	0.48
	Average	7	3.57	0.53	1	5.00	0.00
	Low	6	2.67	1.03	5	2.40	0.89
	Total	19	3.47	0.96	13	3.31	1.03
Sequence of Problem Solving Steps	High	6	2.83	0.98	7	1.29	0.49
	Average	7	0.43	0.53	1	1.00	0.00
	Low	6	0.33	0.52	5	0.20	0.45
	Total	19	1.16	1.34	13	0.84	0.69
Meta-cognitive Strategies	High	6	10.17	5.71	7	6.00	3.16
	Average	7	7.57	2.99	1	5.00	0.00
	Low	6	4.00	2.45	5	1.80	1.48
	Total	19	7.26	4.48	13	4.31	3.17
Cognitive Strategies	High	6	4.83	1.47	7	3.86	2.27
	Average	7	3.14	2.34	1	4.00	0.00
	Low	6	1.33	1.03	5	3.00	2.00
	Total	19	3.11	2.18	13	3.54	2.03

ability students getting the correct sequence more than average ability students, and these in turn getting the correct sequence more than low ability students. A significant interaction resulted from an

Table 5
Analysis of Variance for Selected Student Variables by Level of Teacher Implementation and Level of Student Math Ability

Variable	Source	Sum of Squares	df	Mean Square	F	Probability
Problem Score	Implementation (I)	0.46	1	0.46	5.27	0.03
	Student (S)	2.60	2	1.30	14.97	0.00
	I x S	0.51	2	0.26	2.94	0.07
	Error	2.26	26	0.09		
Total No. Problem Solving Steps	Implementation (I)	0.13	1	0.13	0.23	0.64
	Student (S)	12.49	2	6.24	11.19	0.00
	I x S	2.51	2	1.26	2.25	0.13
	Error	14.51	26	0.56		
Sequence of Problem Solving Steps	Implementation (I)	3.46	1	3.46	8.90	0.01
	Student (S)	23.50	2	11.75	30.22	0.00
	I x S	4.61	2	2.31	5.93	0.01
	Error	10.11	26	0.39		
Meta-cognitive Strategies	Implementation (I)	68.99	1	68.99	5.67	0.03
	Student (S)	161.02	2	80.51	6.64	0.01
	I x S	6.09	2	3.04	0.25	0.78
	Error	315.35	26	12.13		
Cognitive Strategies	Implementation (I)	0.67	1	0.67	0.18	0.67
	Student (S)	28.51	2	14.26	3.87	0.03
	I x S	10.63	2	5.31	1.44	0.26
	Error	95.88	26	3.69		

exceptionally high mean score on the sequence of problem solving steps for high ability students in high implementation classrooms.

Students in high implementation classrooms used significantly more metacognitive strategies than students in low implementation classrooms. There was also a significant difference in the number of metacognitive strategies mentioned among students at the different levels of ability. The order of means favored students who were high in ability over those who were average, and average students over those who were low in math ability. No differences were found in the number of cognitive strategies mentioned among students in the high vs. low implementation classrooms, although there were significant differences among students at the different levels of ability which appeared to originate largely in the high implementation group. Nevertheless, the interaction term was not significant in this analysis.

In sum, students in high implementation classrooms solved the math problem correctly significantly more than students in low implementation classrooms, and they also mentioned the sequence of problem steps correctly significantly more often and mentioned significantly more metacognitive strategies.

Discussion

Students in high implementation classrooms were predicted to use mathematics problem solving steps and learning strategies more than students in low implementation classrooms. Results indicated that students in high implementation classrooms did not use the problem solving steps more often than students in low implementation classrooms. Nevertheless, perhaps of greater import, they did use the problem solving steps in their correct sequence more than students in low implementation classrooms. This combined with the fact that students in high implementation classrooms solved the word problem correctly more than students in low implementation classrooms, suggests that the avenue to correct answers on word problems is through using the problem solving steps in their correct sequence. This conclusion is based on a single word problem, however, and should be replicated to link more clearly the sequence of problem solving steps with correct solutions.

One important conclusion from the findings is that teachers who are provided with staff development activities to introduce problem solving steps and learning strategies to their students appear to do so successfully and with noticeable impact on the strategies students actually use in problem solving. What was also evident, however, is that some of the teachers -- those in low implementation classrooms -- do not participate in the staff development activities with sufficient regularity or intensity to integrate strategy instruction and problem solving steps into their classroom routines. The result appears to be that students in these classrooms not only fail to use the strategies and the correct sequence of problem solving steps, but the students do not obtain correct answers on a word problem as often as students in higher implementation classrooms. Clearly, teachers should be informed of these findings and more teachers should be encouraged to participate in the additional staff development activities needed for them to integrate these approaches in their classrooms.

One of the problems identified in this study was that lower ability students, even when they were in high implementation classrooms, did not tend to use the correct sequence of problem solving steps more than students in low implementation classrooms. Most of the responses accounting for differences in high and low ability classrooms on the correct sequence of problem solving steps originated with higher ability students. Thus, the instructional intervention for problem solving sequence appears to have been successful with students rated higher in ability but not with average or low ability students. One obvious reason is that the successful students were initially identified by their teachers as high math achievers; we expected that they would outperform their classmates on mathematical tasks. Not so obvious is the possibility that they were also operating at a higher level of linguistic competence and may even have been introduced to learning strategies in other classrooms or in their native countries. In addition to the range of factors indicated in Table 2, students represented a range of linguistic competence, from the beginning to the intermediate level of English. Perhaps the fact that average and low achievers were not able to correctly solve the problem is not so much a question of their relative familiarity with learning strategies and problem solving steps, but rather a question of their readiness to deal with mathematical texts in a systematic fashion. Without a rudimentary background in mathematical concepts and the language in which these concepts are taught, students may not be able to apply strategies in a way which leads to the correct answer. Perhaps our focus with students of very limited linguistic, mathematical, and general academic background should also stress other benefits of strategic instruction. For example, by using learning strategies students not only learn a systematic approach to academic tasks, but may also have additional opportunities for practicing the academic language specific to subjects such as mathematics.

Differences on use of metacognitive strategies between high and low implementation classrooms were fairly uniform across levels of student ability. This suggests that high implementation teachers were successful in teaching students at all ability levels to use metacognitive strategies in planning, monitoring, and evaluating their learning. Examples of metacognitive strategy use are provided in the next section.

Conclusion: The Students Speak

This study found substantial differences between strategic and non-strategic ESL students in their approach to solving mathematics word problems in English. Strategic students are those who (1) approached the problem systematically by using problem solving steps in the appropriate sequence; (2) displayed metacognitive awareness and strategies; (3) were able to correctly solve the problem if their mathematics ability was reported as high by their teachers. Non-strategic students, on the other hand, were those who (1) did not take a systematic approach to problem solving; (2) did not display a broad understanding of the problem solving task; (3) lacked the mathematical or linguistic ability to solve the word problem.

In this section we provide examples in students' own words that illustrate the use of a variety of metacognitive strategies and some of the differences in approach of strategic and less strategic students. The following comments from transcripts of high (H), average (A), and low (L) math ability students in high implementation (H) classrooms illustrate the use of a variety of metacognitive strategies:

Organizational Planning

> I'm going to find out: who makes more money, right? Okay (reads part of problem silently), yes, who makes more money, it says that. Plus, I've got to find the name of the person who works more… okay… (reads part of the

problem silently). Okay, it says that Carlos works 8 hours a week, right? 8 hours per week and he gets...

German, High School
H Student, H Teacher

I'm going to use my mind. I'm going to concentrate. I'm going to read it more slowly."

Silvia, Middle School
A Student, H Teacher

(In response to student's plan):
I have to put down numbers and then solve.

Sandra, Middle School
L Student, H Teacher

(NOTE: Her strategy in solving the problem was to put down all the numbers in a column and then add.)

Self-evaluation

Now I have to check it and I check it. I do it correct or wrong. If it's wrong, I will do it again and try to find the answer.

Tu, Middle School
H Student, H Teacher

Selective Attention

This question who works more. (I think . . .) And the second question is who gets more money per week. (I think ...) And the third question is how much more. (90 cents.)

BB, Middle School
H Student, H Teacher

Self-management

When I do work I concentrate to help me more.

Silvia, Middle School
A Student, H Teacher

The following student comments from the transcripts illustrate differences between strategic and non-strategic students in high implementation (H) and low implementation (L) classrooms:

Strategic

(a) Student approached problem systematically:

> First, read it and then find the questions, like what do you know, what do you need to find out...
>
> Karla, Elementary School
> H Student, H Teacher

(b) Student displayed metacognitive awareness:

> (In response to "what strategies are you going to use?"): Ask yourself what do you know. What do you need to find out? What is the progress (meant "process")?
>
> Andy, Elementary School
> A Student, H Teacher

(c) High ability student correctly solved the problem:

> The first question is who works more. Gloria works more than Carlos. The second is who gets more money per week. Gloria gets more money per week. How much more. Ninety cents.
>
> Interviewer: Was that easy for you to do?
>
> Yes, because the first question is who works more. $4.50 times 8 is $36.00 and Gloria is $6.15 times 6. Carlos in 8 hours is $36 per week and Gloria is $36.90 per week.
>
> Marcela, High School
> H Student, H Teacher

Non-strategic

(d) Student did not use systematic approach:

(In response to what strategies student plans to use):

Um, reading and then put down answer.

Manuela, Middle School
L Student, H Teacher

(e) Student did not display broad understanding of task:

Something is wrong.

Aissha, Middle School
H Student, L Teacher

(f) Student lacked mathematical or linguistic ability:

I can't do them (word problems). It's hard. Because I can't read good.

Priya, Elementary School
A Student, L Teacher

These comments provide insight into students' thinking and attitudes towards their own abilities, and are useful for diagnosing difficulties students are encountering in activities such as solving mathematics word problems.

Conclusions reached in this study support the importance of teaching students how to become strategic in their approach to problem solving. A future study might seek to focus more closely on the quality of language and the variety of strategies used by students in high and low implementation classrooms. That is, learning strategy instruction could be examined for its role in inviting the processes of linguistic development as well as the development of strategic behavior, in addition to the impact it has upon enabling students to get the right answer.

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APPENDIX A
WORD PROBLEM PROCEDURE

The CALLA Mathematics curriculum has been supplemented with a Word Problem Procedure (WPP) which Spanos (Arlington Public Schools,, 1991) developed for use in his high school CALLA math class. This procedure is in the form of a one-page worksheet and contains the following 11 steps:

1. Choose a partner or partners. Write your names above.

2. Choose a problem. Write the problem in the space below.

3. Select one student to read the problem aloud. Re-read the problem if necessary. Together, discuss the vocabulary in the problem and circle any words you don't understand. Write the words below.

4. Find the meanings of the words by using a bilingual dictionary, asking your partner(s), or asking your teacher.

5. Write what the problem asks you to find below.

6. Write the operation(s) you need to solve the problem below: Add? Subtract? Multiply? Divide?

7. Solve the problem in the space below.

8. Check your answer.

9. Explain your answer to your partner(s). Write your explanation below.

10. Explain your answer to the class.

11. Write a similar problem on the back of this page.

Steps 1-4 correspond to Step 1 of Polya's method (Understanding the Problem), Steps 5-6 correspond to Step 2 of Polya's method (Devising a Plan), Step 7 to Polyas Step 3 (Carrying out the Plan), and Steps 8-11 to Polyas Step 4 (Looking

Back). The steps in the procedure are analyzed in the curriculum guide in terms of the learning strategies that are involved, e.g., Steps 1-6 are planning steps and therefore invite metacognitive strategies, while Steps 7 and 8 require students to manipulate the mathematical content and therefore involve cognitive strategies. The entire Word Problem Procedure calls on students to use social affective strategies by asking for clarification and working cooperatively on the problem solution. Finally, students use academic language related to mathematics as they read, discuss, write individual explanations of how the problem was solved, and explain to their partners and the class how they arrived at the answer. In this way, the WPP embodies the CALLA philosophy of integrating content, academic language, and learning strategies.

APPENDIX B
INTERVIEW GUIDE FOR THINK-ALOUD AND RESTROSPECTIVE INTERVIEWS
STUDENT INTERVIEW GUIDE

Part I: Warm-Up - Background Information (2 minutes)

1. Introduce self and ask student's name.
2. What is your native language?
3. What country are you from?
4. How long have you been in the U.S.?
5. Did you go to school in your country? What grade did you finish?
6. Explain purpose of interview.

Part II: Think-Aloud Warm-up (3 minutes)

1. Here's an easy problem. Can you tell me what you are thinking while you solve it?

   Student is given a sheet of paper with this problem:

$$\begin{array}{r} 53 \\ -28 \end{array}$$

2. (If student needs more practice with thinking aloud). Do this problem, too:

$$\begin{array}{r} 15 \\ \times 3 \end{array}$$

If student falls silent while working, say TELL ME WHAT YOU'RE THINKING.

Part III: Word Problem Think-Aloud (5 minutes)

1. Start with Word Problem 1. If the student is completely unable to handle it, use Word Problem 2. Say, "Okay, why don't we try this problem instead."

2. Script: "I'd like you to try to solve this problem." (Hand Word Problem 1 to student.) "Here's a pencil and a calculator, if you want to use it. You can write or put anything on this paper to help you solve the problem. Why don't you read the problem aloud first, and then talk aloud while you solve the problem."

   Say TELL ME WHAT YOU'RE THINKING. WHAT STRATEGIES ARE YOU GOING TO USE? If student doesn't understand, say JUST TELL ME WHAT YOU'RE THINKING. WHAT ARE YOU GOING TO DO?

   If, in spite of prompting, student does not want to talk while solving the problem, ask after he or she has completed the problem: "How did you get that answer? Can you tell me what you did?" Have the student go back through each step and describe what he or she did.

WORD PROBLEM 1

Carlos and Gloria work at McDonald's at 4238 Wilson Boulevard. Carlos works 8 hours per week and gets \$4.50 per hour. Gloria works 6 hours per week and gets \$6.15

per hour. Who works more? Who gets more money per week? How much more?

WORD PROBLEM 2 (ALTERNATE)

In 1989, there were 36 students in the HILT math class. In 1990, there were 27 students. Which year had more students? How many more students were there in that year?

Part IV: Learning Strategy Discussion (5 minutes)

Say WHAT STRATEGIES DID YOU USE? if student does not understand, ask WHAT DID YOU DO TO HELP YOU SOLVE THE PROBLEM? if student is not able to generate answers, ask the following questions in sequence:

1. “How did you feel about solving the problem?” (If necessary, ‘Were you nervous? Interested?)

2. “Have you solved other problems like this one?” (if yes, “Did you remember how you did another problem to help with this one?”)

3. “Did you understand the problem right away?” (If no, “What did you do about it?”)

4. “Did you make a plan of what to do?” (If yes, “Tell me about your plan.”)

5. “Did you look for important words to solve the problem?” (If yes, “What were they?”)

6. “Were there any words you didn’t understand?” (If yes, “What were they? Could you solve the problem anyway without those words?”)

7. “How did you decide which numbers to use?”

8. “Did you cross out, or not use, information that you didn’t need?” (If yes, “What was it? What didn’t you need?”)

9. “How did you decide which operation to use?”

10. “Did you make a picture in your head or draw a picture or table?” (If yes, “Can you show/tell me about it?”)

11. “Did you check your answer? (If yes, “How did you do that?”)

THANK YOU FOR YOUR WORK. YOU DID A REALLY GOOD JOB.

APPENDIX C
CALLA TEACHER QUESTIONNAIRE

Teacher Name ____________________ Date____________________

1. Check which of the following math strands you have covered this year:

________ Whole Numbers
________ Fractions
________ Time & Money
________ Ratio & Percent
________ Geometry
________ Decimals
________ Graphs, Charts, Statistics, &
________ Probability
________ Other (Describe______________________________)

2. Check the average amount of time spent on word problems:

_____ once a week _____ 4-5 times a week
_____ 2-3 times a week _____ part of every period

3. Do you think it is necessary to teach learning strategies <u>directly</u> (i.e., to name the strategy and tell why it is important)? __ Yes __ No

Why or why not?

____

____

4. Which learning strategies do you teach directly (D) or indirectly (I)?

__ D __ I Elaborating prior knowledge
__ D __ I Cooperation
__ D __ I Graphic Organizers
__ D __ I Classifying/grouping
__ D __ I Making inferences/predicting
__ D __ I Summarizing
__ D __ I Using images/visualizing

5. Do you teach problem-solving strategies? __ Yes __ No

6. If yes, check which strategies you use*:

__ Finding needed information
__ Finding extra information
__ Cooperative learning
__ Guessing & checking
__ Choosing operations
__ Making organized lists/tables
__ Drawing pictures/diagrams
__ Finding patterns
__ Writing simple problems
__ Solving simpler problems
__ Using logical reasoning
__ Working backward
__ Writing number sentences

7. Additional comments ___________________________________

____

* Problem-solving strategies presented in textbook.