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TEACHING LINKAGE AND PROBLEM TRANSLATING SKILLS IN CHEMISTRY

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This study examines the effects of teaching Linkage and Problem Translating Skills on students' problem-solving performance and their learning of the five cognitive variables namely, Concept Relatedness, Idea Association, Problem Translating Skill, Non-Specific but Relevant Knowledge and Specific Knowledge. Seventy three Grade 9 (Secondary 3) chemistry students in Singapore were involved in this study. The topic for the study was Mole Concept in chemistry. A quasi-experimental design with pre- and post-test measurements was employed. The explicit teaching of Linkage and Problem Translating Skills (treatment), as a teaching problem-solving strategy, and a traditional teaching method (control), were respectively conducted. The results of the study showed that the teaching of the linkage and problem translating skills had improved the students' problem-solving performance and chemistry knowledge.

IDENTIFICATION OF COGNITIVE VARIABLES IN PROBLEM SOLVING

One of the important factors that affect problem solving is the relevant knowledge of basic scientific definitions and principles that exist in the problem solver's mind. Two types of knowledge have been identified as important for solving a subject-related problem (Mayer, 1975; Novak, 1977; Gagné, 1977; Reif & Heller, 1982; Frazer, 1982; Lee, 1985; Anamuah-Mensah, 1986; Camacho & Good, 1989; Schmidt, 1990; Gabel & Bunce, 1994). One is specific knowledge directly related to the problem and the other is non-specific but relevant knowledge to the subject area of the problem. The cognitive variables concerning these two aspects of knowledge are called *Specific Knowledge* (SK) and *Non-Specific but Relevant Knowledge* (NSRK) (Lee, 1985). Since these two variables provide measures of the capacity of the solver's memory store, they are blocked or grouped as a *Prior Knowledge* (PK) variable.

Another important factor that affects problem solving is the integrating and assimilating (subsuming) effects of the cognitive structure. According to Ausubel's cognitive learning theory, meaningful learning involves effective linking between new knowledge and existing cognitive structure (Ausubel, Novak & Hanesian, 1978). Three aspects of linkage are important in the learning processes in science. These include: (1) Internal linkage in a cognitive structure (Novak, 1977; Champagne, Gunstone & Klopfer, 1985); (2) Activation of a particular part of cognitive structure for learning (Mayer, 1975); and (3) External linkage between an existing cognitive structure and the new learning content (Novak, 1977; West, 1975). The first type of linkage is concerned with how effectively or loosely the learner's knowledge is integrated. The second type relates to the accuracy with which a particular part of cognitive structure is retrieved for use in learning a particular piece of new knowledge. The third type is concerned

with the subsumption of concepts that enables the linking of the existing cognitive structure to new concepts or knowledge to be learned.

The two cognitive variables of *Concept Relatedness* (CR) (Johnson, 1965; Novak, 1977; Larkin & Reif, 1979; Larkin, McDermott, Simon & Simon, 1980; Kempa & Nicholls, 1983; Lee, 1985; Sumfleth, 1988; Niaz & Robinson, 1989) and *Idea Association* (IA) (Mayer, 1975; Novak, 1977; Champagne, Gunstone & Klopfer, 1985; Lee, 1985; Sumfleth, 1988; Niaz & Robinson, 1989, 1992) are conceptually related to these three areas of linkage. CR is a measure of the relatedness between concepts that are involved in problem solving which is closely related to the first type of linkage that involves the linkage between the known concepts. IA measures the ability to associate ideas, concepts, words, diagrams or equations through the use of cues which occur in the statements of the problems; it is related to the second and third types of linkage mentioned above. IA involves the retrieval of information from the existing cognitive structure and the linkage between the retrieved information and the external cues. Since these two variables concern linkage measuring the degree of association of the information storage, they are blocked as a *Linkage* (L) variable.

It has also been consistently shown in the literature that problem translating skill (Gagné, 1977; Chi, Feltovitch & Glaser, 1981; Frazer, 1982; Reif & Heller, 1982; Greenbowe, 1983; Lee, 1985; Gabel & Bunce, 1994) and prior problem solving experience (Ashmore, Frazer & Casey, 1979; Frazer & Sleet, 1984; Frazer, 1985; Lee, 1985) are important in determining problem solving performance. *Problem Translating Skill* (PTS) measures the capacity to comprehend, analyse, interpret and define a given problem. *Prior Problem Solving Experience* (PPSE) is a measure of the prior experience in solving the similar problems. Since both these variables seek to measure the problem solver's information processing skills about problem

statements, they are blocked as a *Problem Recognition Skill* (PRS) variable. Table 1 summarizes the three blocks of problem-solving variables and their constituent predictor variables.

Table 1
Determining Variables for Problem Solving

Block Variable	Constituent Predictor Variables
Prior Knowledge (PK)	Specific Knowledge (SK), Non-Specific but Relevant Knowledge (NSRK)
Linkage (L)	Concept Relatedness (CR), Idea Association (IA)
Problem Recognition Skill (PRS)	Problem Translating Skill (PTS), Prior Problem Solving Experience (PPSE)

SOME FINDINGS OF THE PREVIOUS STUDIES ON COGNITIVE VARIABLES IN PROBLEM SOLVING

In Australia, Lee (1985) did a study to investigate cognitive variables of students that affect problem-solving performance in electrochemistry. Two hundred and fourteen Grade 12 chemistry students from six high schools were involved. The study has shown that successful problem solving is related to the above six cognitive variables, namely linkage skills (concept relatedness and idea association), problem recognition skills (problem translating skill and prior problem solving experience) and prior knowledge (specific knowledge and nonspecific but relevant knowledge). The study has also shown that the influence of these cognitive variables on the success of problem solving varies with the familiarity of the problems.

The same study was replicated in Singapore about ten years later to determine if the same cognitive variables had the same influence in problem-solving success, when time and culture were different (Lee, Goh, Chia & Chin, 1996). Two hundred and seventy nine Grade 12 (Pre-U 2) chemistry students from 12 classes in six junior colleges were involved. The study involved the same topic (electrochemistry), the same level (Grade 12), and used the same instruments. The two studies confirm that the above-mentioned cognitive variables, except CR, are significant determining variables of problem-solving performance. IA and PTS are the more important predictors for solving the familiar problem. The five cognitive variables, IA, PTS, PPSE, SK and NSRK, are all significant predictors of problem-solving performance on solving the partially familiar problem. Among them, IA is the most influential predictor. PTS is a significant predictor for the unfamiliar problem.

The above two studies were further extended to a third study which aimed at verifying the importance of the cognitive variables to problem solving in Chemistry across topics and levels. This third study (Lee, Tang, Goh & Chia, 2001) conducted in Singapore involved 115 Grade 9 (Secondary 3) chemistry students solving Mole Concept problems with the familiarity levels ranging from familiar to partially familiar. Four of the five cognitive variables, SK, CR, IA and PTS, were found to be significant in predicting problem-solving performance with IA being the most significant. The study also suggests that the difference in the topics and levels appeared to have little effect on the importance of these variables on problem-solving performance.

Based on the results of the above three studies (two on Electrochemistry at Grade 12 level and one on the Mole Concept at Grade 9 level), it is suggested that an effective problem solving requires: a good understanding of meaningfully learnt knowledge; appropriate problem-solving procedures which include the re-

description of the original problem in a way facilitating the subsequent search for its solution; and relevant linkages of information between the information of problem statements and the existing cognitive structure. Acquisition of knowledge alone does not seem to guarantee a problem-solving success. Certain problem-solving skills such as problem translating skills and linkage skills must be taught.

THE PURPOSE OF THE PRESENT STUDY

As a follow-up of the previous three studies, the present study (the fourth study) was an attempt to teach a problem-solving strategy with emphasis on the two blocked problem-solving skills, namely linkage skills (Concept Relatedness, CR, and Idea Association, IA) and problem recognition skill (Problem Translating Skill, excluding Prior Problem Solving Experience, PPSE, because PPSE is not a teachable variable) to the Grade 9 chemistry students in Singapore. This strategy emphasizing on the teaching of Linkage Skills (Concept Relatedness and Idea Association) and Problem Translating Skill will be called Teaching Linkage and Problem Translation Strategy (TLPTS). The effects of the explicit teaching of this strategy on their problem-solving performance and their learning of the five cognitive variables (SK, NSRK, CR, IA and PTS) were then examined. Mole Concept was chosen for this study because research had shown that many students found it difficult to understand the concepts involved and to apply the concepts to solve Mole Concept problems (Johnstone, 1980; BouJaoude & Barakat, 2000).

RESEARCH QUESTIONS

Two research questions for this study are as follows:

- Q1 Was there a significant difference in the problem-solving performance between the two groups of students, who were taught using Teaching Linkage and Problem Translation

Strategy (TLPTS) and those who were taught using the traditional teaching strategy, on the topic of Mole Concept?

- Q2 Were there significant differences in the problem-solving variables, namely specific knowledge, non-specific but relevant knowledge, concept relatedness, idea association and problem translating skill, between the two groups of students, who were taught using Teaching Linkage and Problem Translation Strategy (TLPTS) and those who were taught using the traditional teaching strategy, on the topic of Mole Concept?

METHOD

Sample

This study involved a total of 73 Grade 9 pure chemistry students with an average age of 15 years, from a government boys' secondary school. The secondary schools in Singapore operate four levels of education which comprise secondary one, two, three and four with ages ranging between thirteen and sixteen years. Two intact classes of average ability were chosen to form a treatment group and a control group. The subjects were taken from two intact classes so as not to upset the normal school routine and organization. The numbers of the students in the treatment and control groups were 37 and 36 respectively.

RESEARCH DESIGN

A quasi-experimental design was adopted since random assignment of subjects was not possible as intact classes were used. The non-equivalent control-group design was used. The same instruments as used in the third study (Lee, Tang, Goh, & Chia, 2001) were used for the pre-test and post-test for both the treatment and control groups. The pre-test and post-test measured the five cognitive

variables, namely CR, IA, PTS, SK and NSRK, and the dependent variable, problem solving performance (PSP), of the students.

The topic, Mole Concept, used for this study was a part of the General Certificate of Education Ordinary Level (GCE 'O' Level) pure chemistry syllabus. Both the control and treatment groups were exposed to the same content knowledge, examples, homework and reading materials. The same teacher (one of the authors, referred to as researcher from here onward) taught both the treatment and control groups so as to minimize the individual differences in teaching styles and in the delivery of course content for the two groups. The students in the two groups were instructed on the TLPTS strategy and the traditional teaching strategy (TTS) respectively. The two strategies were almost identical except for the teaching of Linkage skills (Concept Relatedness and Idea Association) and Problem Translating Skill. While the researcher taught the Linkage Skills and Problem Translating Skill for solving problems to the treatment groups, the researcher used the traditional method (supplying solutions to the problems) to teach problem solving to the control group using the same examples. However, in the TLPTS strategy, the examples were converted into worksheets that were used to train the students in Linkage and Problem Translating Skills. The researcher demonstrated the processes of Linkage and Problem Translation Skills with examples through working with the students on the word association, idea association and problem translation activities. The experiment was carried out over a time frame of five weeks, excluding the time spent on the administration of the pre-test and post-test. Each class had four periods of chemistry theory lessons per week and each period lasted thirty-five minutes. The research design is shown in Figure 1.

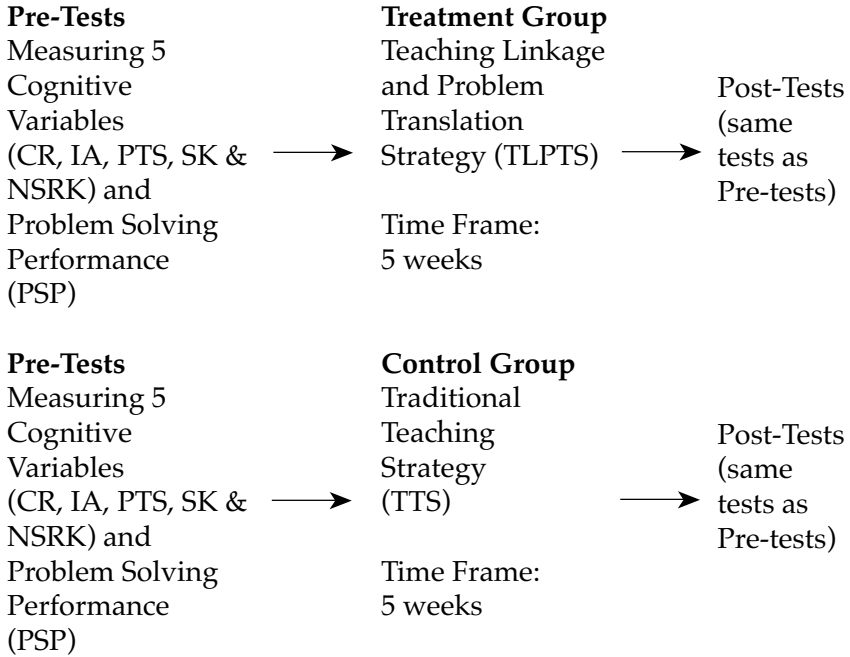


Figure 1: Research Design

TEACHING LINKAGE AND PROBLEM TRANSLATION STRATEGY (TLPTS)

The TLPTS strategy consisted of two teaching components which included the teaching of Linkage skills (Concept Relatedness and Idea Association) and Problem Translating Skill. Concept Relatedness was taught through the word association activity. For the word association activity, the students were asked to do two tasks: (a) word association, (b) generate propositions, when a particular concept or problem solving was being taught in class. These were done through completing worksheets which had the

key concept printed repeatedly in the first column of the worksheets. The students were given one minute to do the word association in the second column and a further three to four minutes to generate propositions in the third column. A word association worksheet as an example is shown in Appendix 1.

Idea Association was taught through the idea association activity. For the idea association activity, students were asked to associate each key word or problem stem, originated from the problem statements of the examples used in class, found in the worksheets to any information available from their minds and put the associative responses in writing on the worksheets. The students were given about one minute for each key word and about three minutes for each problem stem to complete the assigned task. An idea association worksheet as an example is shown in Appendix 2.

As for the teaching of Problem Translating Skill, students were asked to underline the important key words from the problem statement given in the worksheets, to translate the key words into other meanings, to restate the problem statements into their own words, and to set the steps for achieving the solution. The students were given about ten minutes to complete this task for each problem. A problem translating skill worksheet as an example is shown in Appendix 3. A summary of the total number of each type of worksheets given to the students and the time spent on teaching each skill for the whole duration of the treatment is shown in Table 2.

Table 2
Total Number of Each Type of Worksheets Used and Total Time Spent in Training Each Skill

Type of Problem-Solving Skill / Activity	Total No. of Worksheets	Total Time Spent (mins)
Word Association	7	60
Idea Association	7	70
Problem Translating Skill	15	130

TRADITIONAL TEACHING STRATEGY (TTS)

This strategy focused mainly on the teaching of content knowledge of the Mole Concept and its application on problem solving. The strategy was basically teacher-centered. In teaching the application on problem solving, the researcher focused on supplying the solutions for the problems or examples taught. Occasionally, students were asked to show their solutions to the examples given on the whiteboard. Linkage and Problem Translating Skills were not taught and the learning of these problem-solving skills was totally left to chance.

INSTRUMENTS

The same instruments that were used in the previous study (Lee, *et al.*, 2001) were adopted for this present study. The five cognitive variables, CR, IA, PTS, NSRK and SK, were measured by four instruments, namely: (a) Concept Relatedness Test (CRT); (b) Association Test (AT); (c) Problem Translating Test (PTT); and (d) Verbal Knowledge / Intellectual Skill Test (VKIST). The dependent variable (or performance variable), *Problem Solving Performance (PSP)*, was measured by a problem-solving test, the Problem Solving Test for Students (PSTS). Of the five instruments, VKIST and PSTS were the traditional types of tests (multiple-choice questions and a

problem-solving test) while the rest were non-traditional, open-ended types of tests. The design of each instrument is briefly described. The details of the scoring systems for the five instruments were reported in the literature (Lee, *et al.*, 2001)

CONCEPT RELATEDNESS TEST (CRT)

The CRT was used to measure the predictor variable of *Concept Relatedness* (CR). The test consisted of two tasks: (a) word association and (b) generating propositions. The two tasks were used to measure the concept relatedness among the six different key concepts: mole, composition, volume ratio, chemical equation, limiting reagent and relative molecular mass. The six key concepts which served as stimuli were chosen from the most popular specific knowledge related to the six PSTS problems. The individual key concept was printed repeatedly in the first column of the page. Two other columns of spaces were provided side-by-side with the first column of words. The same format was applicable to the other key concepts. The sequence of the key concepts on separate sheets was randomly arranged so that the recall and chaining effects could be reduced.

Association Test (AT)

The AT was used to measure the predictor variable of *Idea Association* (IA), i.e. broader associations activated by the cues in the problem statements. The associative responses could be ideas, concepts, words, diagrams or equations. Two types of cues were used in this test namely, (a) key words and (b) a problem stem, which were taken from the problem statements of the PSTS. In total, seven key words and six problem stems were used and arranged in a random order. Enough space was provided for the students to list all the possible associations. The information retrieved by the cues from the same problem statement was considered as part of a cognitive structure that had been provoked and hence the retrieved information was

likely to be available for use in solving the particular problems in the Problem Solving Test for Students.

Problem Translating Test (PTT)

This test was used to measure the predictor variable for the *Problem Translating Skill* (PTS). Six parallel problems to the six problems of PSTS were set in this test. The parallel problems, instead of the original problems from PSTS, were used so that the possible recall effect could be reduced during the solving of PSTS. The four instructions, designed for use with each problem, were:

- (1) Underline in this problem statement the key (important) pieces of information needed for its solution.
- (2) For each piece of information you have underlined, describe what it means in your own words.
- (3) List the steps you would use to solve the problem.
- (4) If possible, try to write the same problem using other words.

Verbal Knowledge/Intellectual Skill Test (VKIST)

This was a test of 20 multiple choice items on the topic of Mole Concept. The test was divided into two sections, Section A and Section B. Section A consists of ten questions which measured one of the predictor variables, *Non-Specific but Relevant Knowledge* (NSRK). Section B consisted of another ten questions which measured the *Specific Knowledge* (SK).

Problem Solving Test for Students (PSTS)

The PSTS was designed to measure the dependent variable of *Problem Solving Performance* (PSP). It consisted of six Mole Concept problems as shown in the Appendix 4. The problem-solving performance for each problem was scored based on the three systems: (1) problem-solving score; (2) explicit use of appropriate knowledge; and (3) correct application of appropriate algorithms.

ADMINISTRATION OF INSTRUMENTS

The same five instruments were administered to the students before and after they were taught the topic of Mole Concept as pre-test and post-test respectively. The tests were conducted over three sessions repeatedly for both the pre-test and post-test, two of which took 55 minutes each and the final session took 30 minutes. The distribution of the time allocation for administering these five instruments in the three sessions was: (i) Session 1 – CRT: 30 mins, AT: 25 mins; Session 2 – VKIST: 25 mins, PTT: 30 mins; Session 3 – PSTS: 30 mins.

RESULTS

The Cronbach a reliabilities were calculated for the responses from all the five instruments. Descriptive statistics such as the means, standard deviations and maximum score possible for the tests were also calculated. For the inferential statistics, a multivariate analysis of variance (MANOVA) of the pre-test variables scores (five cognitive variables, CR, IA, PTS, NSRK and SK; Problem Solving Performance, PSP) comparing the treatment and control groups was first conducted to identify any pre-existing differences. Once the initial pre-test differences were identified, a multiple analysis of covariance (MANCOVA) of the variables' post-test scores was then conducted taking into consideration the covariates identified. This would determine the effects of the treatment on the students' problem-solving performance and their learning of the five cognitive variables.

RELIABILITY OF THE INSTRUMENTS

The Cronbach a reliabilities of all the five instruments are presented in Table 3. The scoring systems used for scoring all the five instruments involved a number of scoring items (see Lee, *et al.*, 2001). The numbers of the items involved in the scoring systems for all

the instruments are also shown in Table 3. Among the five instruments, the reliability values for the VKIST test, Section A and Section B, were found to be quite low. The low reliability values might be attributed to the fact that the test only used a few questions (ten multiple choice questions each) and that the students had little variations in their performance.

Table 3
Reliabilities of the Instruments

Instrument	Variable	Cronbach α	No. of items
1. CRT (Overall)	CR	0.93	30
2. AT (Overall)	IA	0.82	13
3. PTT (Overall)	PTS	0.69	12
4. VKIST (Section A)	NSRK	0.19	10
5. VKIST (Section B)	SK	0.39	10
6. PSTS (Overall)	PSP	0.83	18

DESCRIPTIVE STATISTICS

The means, standard deviations and maximum scores possible of all the cognitive variables of the pre-test and post-test variables scores between the treatment and control groups are shown in Table 4 and Table 5 respectively. There were some missing values in each variable because some students were either absent or did not complete the tests. The mean scores of the three non-traditional tests, Concept Relatedness Test (CRT), Association Test (AT) and Problem Translating Test (PTT), were low. This indicated that the students were generally weak in linking concepts, rules and facts and in translating the problem statements. In addition, the students were not comfortable with or used to the three non-traditional tests.

Table 4
Descriptive Statistics for the Pre-Test Variables Scores between the Treatment and Control Groups

Instruments	Variable	Treatment Group Mean (S.D.) (N=36)	Control Group Mean (S.D.) (N=35)	Max. Score Possible
1. CRT (Overall)	CR	3.68 (2.45)	2.17 (1.80)	30
2. AT (Overall)	IA	13.75 (4.93)	8.06 (4.84)	@
3. PTT (Overall)	PTS	6.97 (5.24)	5.29 (3.64)	@
4. VKIST (Section A)	NSRK	4.89 (1.77)	4.03 (1.65)	10
5. VKIST (Section B)	SK	4.86 (1.50)	4.00 (1.86)	10
6. PSTS (Overall)	PSP	11.06 (5.32)	5.66 (5.13)	48

@ No "max. score possible" due to open-ended questions.

Table 5
Descriptive Statistics for the Post-Test Variables Scores between the Treatment and Control Groups

Instruments	Variable	Treatment Group Mean (S.D.) (N=35)	Control Group Mean (S.D.) (N=30)	Max. Score Possible
1. CRT (Overall)	CR	4.51 (2.36)	2.70 (2.54)	30
2. AT (Overall)	IA	25.29 (8.98)	14.93 (8.98)	@
3. PTT (Overall)	PTS	20.89 (10.71)	13.23 (9.24)	@
4. VKIST (Section A)	NSRK	8.63 (1.14)	7.67 (1.21)	10
5. VKIST (Section B)	SK	8.00 (1.37)	7.03 (1.52)	10
6. PSTS (Overall)	PSP	24.63 (10.05)	13.53 (6.79)	48

@ No "max. score possible" due to open-ended questions.

MANOVA ANALYSIS

A multivariate analysis of variance (MANOVA) of the variables' pre-test scores was conducted to identify any pre-existing differences in Problem-Solving Performance (PSP), Concept Relatedness (CR), Idea Association (IA), Non-Specific but Relevant Knowledge (NSRK), Specific Knowledge (SK) and Problem Translating Skill (PTS) between the treatment and control groups of students. Table 6 shows the results of the MANOVA analysis. From Table 6, the pre-test scores of CR, IA, NSRK, SK, and PSP between the treatment and control group were significantly different. These five variables would be taken into consideration when the data were further analyzed to determine the answers for the two research questions.

Table 6
MANOVA on the Pre-test Variables Scores of the Five Cognitive Variables and Problem Solving Performance between the Treatment and Control Groups

Source	Type III SS	df	MS	F-Ratio	P-Value
CR	40.76	1	40.76	8.76	0.004*
IA	575.14	1	575.14	24.07	0.000*
PTS	50.48	1	50.48	2.47	0.121
NSRK	13.14	1	13.14	4.48	0.038*
SK	13.16	1	13.16	4.63	0.035*
PSP	517.18	1	517.18	18.92	0.000*

* Significant p-value

MANCOVA ANALYSIS

Two statistical hypotheses, as shown in Sections 3.4.1 and 3.4.2, were formulated to answer the two research questions as mentioned earlier. Five covariates, CR, IA, NSRK, SK, and PSP were identified in the MANOVA analysis of pre-test scores (Table 6) that showed the pre-existing differences between the two groups. Using the pre-test scores of CR, IA, NSRK, SK, and PSP as covariates, a multiple analysis of covariance (MANCOVA) of the post-test scores of Problem Solving Performance, PSP, and the five cognitive variables, CR, IA, PTS, NSRK and SK, between the treatment and control groups were conducted respectively.

EFFECT OF TLPTS STRATEGY ON PROBLEM SOLVING PERFORMANCE

Null Hypothesis I

“There was no significant difference in the problem solving performance between the two groups of students, who were taught using Teaching Linkage and Problem Translation Strategy (TLPTS) and those who were taught using the traditional teaching strategy, on the topic of Mole Concept.”

The results of MANCOVA analysis on the post-test scores of Problem Solving Performance (PSP) using the pre-test scores of CR, IA, NSRK, SK and PSP as covariates, are shown in Table 7. The p-value was 0.008. Thus, the null hypothesis was rejected. This indicated that the treatment had an effect on the students' Problem Solving Performance at the significant level of 0.008.

Table 7
MANCOVA on the Post-Test Scores of PSP between the Treatment and Control Groups Using the Pre-Test Scores of CR, IA, NSRK, SK, and PSP as Covariates

Source	Type III SS	df	MS	F-Ratio	P-Value
Intercept	199.89	1	199.89	3.40	-
CR (Pre-scores, Covariate)	9.28	1	9.28	0.16	-
IA (Pre-scores, Covariate)	1.97	1	1.97	0.03	-
NSRK (Pre-scores, Covariate)	43.54	1	43.54	0.74	-
SK (Pre-scores, Covariate)	109.27	1	109.27	1.86	-
PSP (Pre-scores, Covariate)	691.94	1	691.94	11.77	-
Treatment (Between)	448.65	1	448.65	7.63	0.008*
Error (Within)	3410.01	58	58.79		
Total	31494.00	65			

* Significant p-value

The treatment group of students who were taught Linkage Skills and Problem Translating Skills explicitly showed significantly better problem-solving performance compared to that of the control group who was not taught these problem-solving skills. For the post-test scores of PSP, the mean of the students from the treatment group was about 11 marks more than that of the students from the control group (Table 5). Thus, it was found that the explicit teaching of Linkage and Problem Translating Skills did enhance the problem-solving performance.

EFFECT OF TEACHING TLPTS STRATEGY ON THE FIVE COGNITIVE VARIABLES

Null Hypothesis II

“There are no significant differences in the problem-solving variables, namely specific knowledge, non-specific but relevant knowledge, concept relatedness, idea association and problem translating skill, between the two groups of students, who were taught using Teaching Linkage and Problem Translation Strategy (TLPTS) and those who were taught using the traditional teaching strategy, on the topic of Mole Concept.”

The results of MANCOVA analysis on the post-test scores of the five cognitive variables, CR, IA, PTS, NSRK and SK, using the pre-test scores of CR, IA, NSRK, SK and PSP as covariates, are shown in Table 8. NSRK and SK were significant at 0.056 and 0.108 confidence levels. These results indicated that among the five cognitive variables, the treatment had a significant effect on the students' Non-Specific but Relevant Knowledge (NSRK) and Specific Knowledge (SK). The treatment had no effect on Concept Relatedness (CR), Idea Association (IA), and Problem Translating Skill (PTS). Thus, the null hypothesis was partially rejected.

Table 8
Comparison of the Post-Test Scores of the Five Cognitive Variables, CR, IA, PTS, NSRK and SK, between the Treatment and Control Groups Using the Pre-Test Scores of CR, IA, NSRK, SK and PSP as Covariates

Cognitive Variable	F-Ratio	P-Value
CR	0.27	0.604
IA	1.97	0.166
PTS	0.84	0.362
NSRK	3.79	0.056*
SK	2.67	0.108*

* Significant p-value

DISCUSSION

Findings from the three previous studies (Lee, 1985; Lee, *et al.*, 1996, 2001) showed that the Linkage skills (Concept Relatedness and Idea Association), Problem Translating Skill and Prior Knowledge were important predictors of problem-solving performance in chemistry. This paper addresses the issue on the actual teaching of these three problem-solving skills in the classroom and also addresses the effect of teaching the TLPTS strategy on the problem-solving performance of students. In addition, the effects of the treatment on the five cognitive variables of problem solving, CR, IA, PTS, NSRK and SK, were also explored.

In this study, the researchers found that the teaching of the TLPTS strategy had a very significant effect on the students' problem-solving performance in the Mole Concept (Table 7). This confirmed the researchers' findings in the earlier studies (Lee, 1985; Lee, *et al.*, 1996, 2001) that the problem-solving skills, such as CR, IA and PTS were important cognitive variables in problem solving. However,

the effects of the teaching of the TLPTS strategy on the five cognitive variables varied (Table 8). The treatment group had shown a significant improvement in the two prior knowledge variables, Non-Specific but Relevant Knowledge (NSRK) and Specific Knowledge (SK), but not the other three treatment variables, Concept Relatedness (CR), Idea Association (IA), and Problem Translating Skill (PTS), as compared to the control group. Nevertheless, these results indicated that the treatment had facilitated the students' problem-solving performance and also the acquisition of the chemistry knowledge. The three previous studies had consistently shown that all the five cognitive variables were related to problem-solving performance. It led the researchers to believe that the students of the treatment group who showed improvement in problem solving, to some extent, could have transferred the three problem-solving skills (CR, IA and PTS) learnt to solve the problems, even though they did not learn these skills effectively.

The teaching of the TLPTS strategy had an effect on overall problem-solving performance and yet it appeared to have no effect on the variables (CR, IA and PTS) which were directly related to the treatment. The absence of improvement in CR, IA and PTS among the treatment group of students might be attributed to the following two reasons:

1. The three tests used to measure the three variables, CR, IA and PTS were non-traditional tests that had never been used in the school before the treatment. Furthermore, the students knew very well that these types of tests were "non-high-stake" tests that would not be used as part of the school assessment or the external O-level examination. For this reason, they were not serious enough in attempting these tests as compared to the other two traditional tests (knowledge test and problem solving test) which were "high-stake" tests. Hence, the students' improvements in these skills were probably not reflected in their scores.

2. A five-week treatment (4 periods per week) on the three problem-solving skills might not be sufficient. It might have been more effective if the treatment had been conducted over a longer period of time.

The literature has shown that the linkage of concepts can be more effective when the concepts are meaningfully learned (Ausubel, Novak & Hanesian, 1978). Other teaching strategies, such as concept mapping (Novak, 1984), concept analysis (Herron, 1996) and constructivist approach (Fensham, Gunstone & White, 1994), that emphasize on meaningful learning can also be incorporated when teaching Concept Relatedness and Idea Association.

Likewise, the students can be encouraged to practise more on how to translate the problem in order to make sense of the problem statements. For instance, they can identify the key words from the problem statements and translate them into other meanings, represent the problem statements by drawing out the diagrams, re-state the problem statements into their own words and set the steps for arriving at the solutions. The researchers believe that a longer time frame for carrying out the treatment can further improve the learning outcomes of Concept Relatedness, Idea Association, and Problem Translating Skill.

IMPLICATIONS

The findings of this study have shown that the learning of specific problem-solving skills, such as linkage and problem translating skills, can improve the learning of chemistry knowledge and problem-solving performance. Students should be taught problem-solving skills explicitly and ample opportunities should be given to them to practise the skills if the acquisition of these problem-solving skills is expected to take place in a classroom environment. Furthermore, for the teaching of the skills to be effective, it is suggested that a longer period of time should be used and the

teachers should be properly trained in the teaching of the above three problem-solving skills. Careful planning and selection of appropriate examples or problems for students to practise on is another important aspect to be considered for effective teaching of the afore-mentioned skills.

Some courses on the teaching of problem-solving skills can be included in the pre-service training of teachers to prepare them adequately for teaching these problem-solving skills, as well as during in-service training for teacher practitioners who are at the frontline teaching the students. Textbooks writers can also play a part to support the teachers in the teaching of problem-solving skills. The writers can incorporate the training of these skills in their textbooks by including carefully planned exercises for the students to practise.

Appendix 1. Word Association Worksheet

Instructions

- On each page you will find the same word / term written many times.
- From your knowledge of Chemistry, write down in column 2 all the words that come to your mind when you think of the word / term in column 1.
- Do not use column 3 at this stage.
- Do not worry about spelling and write as many words as you can.
- In column 3, generate a phrase or a sentence to connect the word in the column 1 and the word that you responded in column 2 to show a relationship between them.

mole

1. mole _____

2. mole _____

3. mole _____

4. mole _____

5. mole _____

6. mole _____

7. mole _____

8. mole _____

9. mole _____

10. mole _____

Appendix 2. Idea Association Worksheet

Instructions

- In this test there are a number of chemical words and ideas.
- From your knowledge of chemistry, write as many other phrases or sentences as you can which involve these words or ideas. Also draw any diagrams that come to mind when you think of these words or ideas.
- There are many right answers. Do not worry about spelling.

Eg.1. decomposition of calcium carbonate

(a) _____

(b) _____

(c) _____

(d) _____

(c) _____

(d) _____

Eg.2. 8 g of oxygen react with 1 g of hydrogen

(a) _____

(b) _____

(c) _____

(d) _____

Appendix 3. Problem Translation Worksheet

Instructions

- In this exercise, we want to find out how you begin to interpret a problem before you actually work it out.
- Read the problem carefully and follow the instructions given with face problem.
- It is NOT necessary to solve the problems.

Problem

In one particular experiment it is found that 8 g of oxygen react exactly with 1 g of hydrogen to give 9 g of water. What is the mass of water expected from the combination of 3 g of hydrogen with 16 g of oxygen ?

1. Underline in this problem statement the key (important) pieces of information needed for its solution.
2. For each piece of information you have underlined, describe what it means in your own words.

(a) first piece of information

(b) second piece of information

(c) third piece of information

(d) fourth piece of information

(e) fifth piece of information

3. List the steps you would use to solve the problem.
4. If possible, try to write the same problem but using other words.

Appendix 4. The six problems of Problem Solving Test for Students

Problem 1

How many modules of the atoms of B (Boron) are present in a sample having 2×10^{23} molecules of B_4H_{10} ?

Problem 2

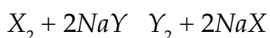
In one particular experiment it is found that 8 g of oxygen reacts exactly with 1 g of hydrogen to give 9 g of water. What is the mass of water expected from the combination of 3 g of hydrogen with 16 g of oxygen?

Problem 3

Epsom Salt is the name given to a hydrated form of magnesium sulphate $MgSO_4 \cdot xH_2O$, where x is an integer (whole number). When Epsom Salt is heated until all of the water is driven off. A student finds that heating the Epsom Salts causes a mass loss of slightly more than 50%. Determine the value of x in $MgSO_4 \cdot xH_2O$.

Problem 4

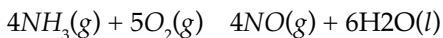
The element X has a relative atomic mass of 35.5. It reacts with a solution of the sodium salt of Y according to the equation:



If 14.2 g of X_2 displace 50.8 g of Y_2 , determine the relative atomic mass of Y.

Problem 5

In the Ostwald process for making nitric acid, ammonia and oxygen are passed over heated platinum catalyst to yield nitrogen monoxide and water.



If 500 cm_3 of ammonia and 500 cm_3 of oxygen were used, determine the composition of the resulting gas mixture.

(All gaseous volumes are measured at r.t.p.)

Problem 6

On decomposition of 50 g of calcium carbonate, 28 g of calcium oxide and 22 g of carbon dioxide were obtained. What is the composition of calcium carbonate if calcium oxide contains 5 parts by mass of calcium and 2 parts by mass of oxygen, and carbon dioxide contains 3 parts by mass of carbon and 8 parts by mass of oxygen?

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