CHEMISTRY EDUCATION: RESEARCH AND PRACTICE IN EUROPE
2001, Vol. 2, No. 3, pp. 285-301

RESEARCH REPORT
Problem solving and other higher-order cognitive skills (HOCS)

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THE PREDICTING ROLE OF COGNITIVE VARIABLES IN PROBLEM SOLVING IN MOLE CONCEPT

Received 28 February 2001; revised 31 May 2001; accepted 11 June 2001

ABSTRACT: This work is an extension of the two previous studies which aims at verifying the importance of the cognitive variables to problem solving in Chemistry across topics and levels. The previous studies show that the five cognitive variables namely, Specific Knowledge, Non-Specific but Relevant Knowledge, Concept Relatedness, Idea Association and Problem Translating Skill, are the important predictors of problem-solving performance in the topic of Grade 12 Electrochemistry. This present study involved 115 Grade 9 Chemistry students, aged between 13 and 16, solving Mole Concept problems with the familiarity levels ranging from familiar to partially familiar. Four of the five cognitive variables, Specific Knowledge, Concept Relatedness, Idea Association and Problem Translating Skill, have been found to be significant in predicting problem-solving performance with Idea Association 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. [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 285-301]

KEY WORDS: *problem solving; cognitive variables; mole concept*

INTRODUCTION

Instruction in science is generally aimed at achieving two goals. The first is the acquisition of a body of organised knowledge in a particular domain. Beyond the mere acquisition of knowledge in a particular domain, the second important goal in science instruction is the ability to solve problems in that domain (Gabel and Bunce, 1994; Tsaparlis, Kousathana and Niaz, 1998; Heyworth, 1999; Stamovlasis and Tsaparlis, 2000). In order to achieve this second goal of solving problems in science, there are two issues to be addressed. First is the understanding of the significance of teaching problem solving in science education. Due to the nature of the subject, scientists very often conduct experiments to verify or prove certain hypotheses that they have formulated. During the process of working from the area of known facts to an area of uncertainties, many problems may arise. Scientists must be capable of overcoming or solving the obstacles or problems that arise to achieve their goals ultimately. It is therefore important to develop in students problem-solving skills through science education.

Since problem solving is important in science education, the next issue then would be to look at the difficulties faced by students in this area and find ways to help them overcome these difficulties. In their recent review of research studies on problem solving in chemistry, Gabel and Bunce (1994) find that many students do not understand the chemistry concepts involved in chemistry problems or are unable to apply the conceptual knowledge in solving the problems. They mainly use algorithms or principles to arrive at correct answers. One of the solutions being suggested is to teach the students certain problem-solving skills or cognitive strategies and variables to solve the problems (Lee, 1985; Bunce, Gabel and Samuel, 1991; Niaz, 1995; Lee, Goh, Chia and Chin, 1996; Lee and Fensham, 1996; Tsaparlis and Angelopoulos, 2000).

COGNITIVE VARIABLES OF 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 and Heller, 1982; Frazer, 1982; Lee, 1985; Anamuah-Mensah, 1986; Camacho and Good, 1989; Schmidt, 1990; Gabel and 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 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 and Hanesian, 1978). Three aspects of linkage are important in learning processes in science. These include: (1) Internal linkage in a cognitive structure (Novak, 1977; Champagne, Gunstone and 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 and Reif, 1979; Larkin, McDermott, Simon and Simon, 1980; Kempa and Nicholls, 1983; Lee, 1985; Sumfleth, 1988; Niaz and Robinson, 1989) and *Idea Association* (IA) (Mayer, 1975; Novak, 1977; Champagne, Gunstone and Klopfer, 1985; Lee, 1985; Sumfleth, 1988; Niaz and 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 and Glaser, 1981; Frazer, 1982; Reif and Heller, 1982; Greenbowe, 1983; Lee, 1985; Gabel and Bunce, 1994) and prior problem solving experience

(Ashmore, Frazer and Casey, 1979; Frazer and 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)

THE STUDY

Lee (1985) did a study in Australia to investigate cognitive variables that affect problem-solving performance in electrochemistry. Two hundred and fourteen Grade 12 chemistry students from six high schools were involved in the study. The study has shown that successful problem solving is related to several important cognitive variables which can be grouped as block 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 non-specific but relevant knowledge). These block variables consist of predictor variables as shown in the above brackets. In addition, the influence of these predictor variables on the success of problem solving varies with the familiarity of the problems.

The same study was replicated in Singapore to determine if the same cognitive variables had the same influence in problem-solving performance, when time and culture were different (Lee *et al*., 1996). Two hundred and seventy nine pre-university 2 (equivalent to Grade 12) chemistry students from 12 classes of six junior colleges were involved. The findings of these two studies (Lee *et al*., 1996) are consistent and link the success of problem-solving to adequate translation of problem statement, relevant linkage between problem statement and knowledge, and correctness of prior knowledge retrieved. However, to what extent can we generalise that these cognitive variables are also important in solving other type of chemistry problems, such as the different topics and levels? Further study is therefore required to seek for an answer to the above question. This forms the basis of the present study, which is an extension of the two studies done earlier (Lee, 1985; Lee *et al*., 1996).

The aim of this study is to investigate the effect of the five cognitive variables (except for *Prior Problem Solving Experience*) on problem-solving performance in Mole Concept. Mole Concept is chosen for this study because research has shown that many students find it difficult to understand the concepts involved and to apply the concepts to solve Mole Concept problems (Johnstone, 1980; BouJaoude and Barakat, 2000). It is important to find out what cognitive variables determine the success of problem solving in Mole Concept so that teachers can emphasise their teaching of problem solving in these cognitive variables. In this study, the variable of *Prior Problem Solving Experience* was not included because it is not a teachable variable. The students can gain problem-solving experience through practice. The research question for this study is:

> In what way is the problem-solving performance in Mole Concept at Grade 9 level related to the three block predictor variables, namely *Prior Knowledge* (PK), *Linkage* (L) and *Problem Recognition skills* (PRS); and the five cognitive variables of problem solving, namely: *Specific Knowledge* (SK), *Non-Specific but Relevant Knowledge* (NSRK), *Concept Relatedness* (CR), *Idea Association* (IA) and *Problem Translating Skill* (PTS) *respectively*?

METHOD

Samples

The study involved 115 Grade 9 chemistry students (age ranging between 13 and 16 years old) from a government boys' secondary school in Singapore. The investigation was conducted by designing and administering tests to students to assess their problem-solving ability and skills in solving problems on the topic of Mole Concept.

Variables and instruments

For the five cognitive variables mentioned previously, the predictor variables 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). They were used to measure the five predictor variables, CR, IA, PTS, NSRK and SK. The dependent variable (or performance variable), *Problem Solving Performance* (PSP), was measured by a problem-solving test, the Problem Solving Test for Students (PSTS). The six variables and five instruments are summarised in Table 2.

Of the five instruments, two were traditional type of tests (multiple-choice questions and problem-solving test) while the rest were non-traditional, open-ended type of tests. All the five instruments were designed based on the content of Mole Concept, but their formats were modelled upon similar instruments used in Lee's (1985) study done in Australia. The

TABLE 2: *Problem-solving variables and instruments.*

Variables	Instruments	Type of Instruments
Concept Relatedness (CR)	Concept Relatedness Test (CRT)	Non-traditional
Idea Association (IA)	Association Test (AT)	Non-traditional
Specific Knowledge (SK)	Verbal Knowledge / Intellectual Skill Test (Section A) (VKIST)	Multiple-Choice Questions
Non-Specific but Relevant Knowledge (NSRK)	Verbal Knowledge / Intellectual Skill Test (Section B) (VKIST)	Multiple-Choice Questions
Problem Translating Skill (PTS)	Problem Translating Test (PTT)	Non-traditional
Problem Solving Performance (PSP)	Problem Solving Test for Students (PSTS)	Traditional Problem Solving

scoring systems for the five instruments were devised. The design of each instrument is briefly described.

Problem Solving Test for Students (PSTS)

The PSTS was designed to measure the dependent variable of *Problem Solving Performance* (PSP). It consists of six problems as shown in the Appendix. The six problems are the Mole Concept problems with the familiarity level ranging from familiar to partially familiar. Unfamiliar problems were not used in this study. The familiarity level of these problems was classified based on the definitions provided. "Familiar" problems refer to the problems which are similar to the questions that have been set in O-level examinations or used in the textbooks. "Partial familiar" problems refer to the problems which are in part similar to the questions having been set in O-level examinations or used in the textbooks. "Unfamiliar" problems refer to the problems which have not appeared either in O-level examinations or in the textbooks. Since these classes were being prepared for the Grade 10 (O-level) external examination to be taken place in the year after, only familiar and partially familiar problems or similar and partly similar to the O-level examination or textbook problems were therefore designed for this study. Problem 1 is a familiar type of problem which concerns the relationship between number of particles and number of moles of a substance. Problem 2 is a partially familiar problem which concerns the concept of limiting reagent and excess reagent in a reaction. Problem 3 is a familiar problem which concerns the determination of chemical formula of a compound. Problem 4 is a familiar problem which concerns the calculation of relative atomic mass and relative molecular mass of chemicals involved in a reaction. Problem 5 is a partially familiar problem which concerns the limiting and excess reagents in a reaction involving gases. Problem 6 is a familiar problem which concerns the determination of the composition of a compound. Four of the six problems (Problems 1, 3, 4 and 6) are familiar problems whereas the other two problems (Problems 2 and 5) are partially familiar problems. 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. The overall *Problem Solving Performance* (PSP) is the sum of the six problem-solving performance scores.

Concept Relatedness Test (CRT)

The CRT was used to measure the predictor variable of *Concept Relatedness* (CR). The test consists of two tasks: (a) word association and (b) generating propositions. These 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 is printed repeatedly in the first column of the page. Two other columns of spaces are provided side-by-side with the first column of words. The same format is applicable to the other key concepts. The sequence of the key concepts on separate sheets is randomly arranged so that the recall and chaining effects can be reduced.

For the first task, the students were given one minute to write down in column two, from their chemistry knowledge, words that came to their mind each time they saw the key concept in column one. Once this task was completed, the second task of generating propositions by writing a phrase or sentence in column three was continued. The second task was used to validate the responses to see if the responses were relevant within the domain of chemistry.

Two measures of the word responses were considered in scoring this test, namely, (1) word responses with or without propositions generated and (2) word responses with propositions generated. The reason for considering both measures is that some students might have difficulties in putting words together in generating the propositions. ‘No proposition’ did not necessarily indicate inadequate association between the word response and the stimuli. The Garstof and Houstons’ formula on relatedness coefficient (1963) for measuring the relatedness of two words was employed. Fifteen relatedness coefficients were computed for each pair of the six key concepts. The sum of the fifteen relatedness coefficients for each measure was further calculated.

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) problem stem, which were taken from the problem statements of PSTS. In total, seven key words and six problem stems were used and arranged in 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 cognitive structure that had been provoked and the retrieved information hence was likely to be available for use in solving the particular problems. Six sets of relevant information for the six respective problems were devised and used as guidelines for scoring the test. The responses to the cues given in the test (13 items in total) were identified as relevant or irrelevant by referring to these guidelines. The scores for this test consist of the total numbers of the relevant information for each problem, and for the overall problem, IA, which is the sum of the total number of relevant information for all the six problems.

Problem Translating Test (PTT)

This test is used to measure the predictor variable of *Problem Translating Skill* (PTS). 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, are:

(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 but use other words.

In scoring this test, two measures namely, (1) comprehending, analysing and interpreting, and (2) defining, were involved. The marking keys were devised for use as the guidelines for scoring the responses.

Verbal Knowledge / Intellectual Skill Test (VKIST)

This is a test of 20 multiple choice items on the topic of Mole Concept. The test is divided into two sections, Section A and Section B. Section A consists of 10 questions which measure one of the predictor variables, *Non-Specific but Relevant Knowledge* (NSRK). Section B consists of another 10 questions which measure the *Specific Knowledge* (SK). As traditional, correct and incorrect answers were scored as 1 and 0 for each item respectively.

Administration

The five instruments were administered to the students after they were taught the topic of Mole Concept. The tests were conducted over three sessions, two of which lasted 55 minutes each and the final session lasted 30 minutes. The sequence and the time allocation for administering these five instruments in the three sessions are shown in Table 3.

TABLE 3: *Sequence and time allocation for administering the five instruments.*

Session	Instrument	Approx. Time Allocation (mins)
1	CRT	30
	AT	25
2	VKIST	25
	PTT	30
3	PSTS	30

RESULTS

The Cronbach α reliabilities were calculated for all the five instruments. Descriptive statistics such as the means, standard deviations and ranges of the scores for the tests were also calculated. Correlation analyses were done to determine the relationships among the variables (five predictor variables and one dependent variable). In addition, multiple regression analyses were conducted for the overall problem and for each of the six problems in the PSTS with respect to the three block predictor variables and the five individual predictor variables. This was done to determine whether all the block predictor variables and the individual predictor variables contribute significantly to successful problem solving.

Reliability of the instruments

The Cronbach α reliabilities of all the five instruments are presented in Table 4. The scoring systems used for scoring all the five instruments, involved a number of scoring items. The number of the items involved in the scoring systems for all the instruments are also shown in Table 4.

Descriptive statistics

The means, standard deviations and ranges of all the cognitive variables are shown in Table 5. The results show that the mean scores of the three non-traditional tests, Concept Relatedness Test (CRT), Association Test (AT) and Problem Translating Test (PTT) were low, especially for CRT. This indicates that the students were generally weak in linking to

TABLE 4: *Reliabilities of the instruments.*

	Instrument	Variable	Cronbach α	No. of items
1.	CRT (Overall)	CR	0.93	30
2.	AT (Overall)	IA	0.81	13
3.	VKIST (Section A)	NSRK	0.39	10
4.	VKIST (Section B)	SK	0.44	10
5.	PTT (Overall)	PTS	0.69	12
6.	PSTS (Overall)	PSP	0.82	18
7.	PSTS (Problem 1)	PSP1	0.88	3
8.	PSTS (Problem 2)	PSP2	0.84	3
9.	PSTS (Problem 3)	PSP3	0.83	3
10.	PSTS (Problem 4)	PSP4	0.72	3
11.	PSTS (Problem 5)	PSP5	0.88	3
12.	PSTS (Problem 6)	PSP6	0.85	3

TABLE 5: *Descriptive statistics.*

	Instrument	Variable	Mean	S.D.	Range	Max. Score Possible
1.	CRT (Overall)	CR	3.38	2.48	11	30
2.	AT (Overall)	IA	24.77	10.72	45	*
3.	AT (Problem-1)	IA1	3.67	1.76	9	*
4.	AT (Problem-2)	IA2	5.14	2.75	13	*
5.	AT (Problem-3)	IA3	3.71	2.10	9	*
6.	AT (Problem-4)	IA4	3.51	2.21	12	*
7.	AT (Problem-5)	IA5	2.82	2.14	8	*
8.	AT (Problem-6)	IA6	5.91	3.72	14	*
9.	VKIST (Section A)	NSRK	7.77	1.54	6	10
10.	VKIST (Section B)	SK	7.60	1.48	8	10
11.	PTT (Overall)	PTS	15.41	9.91	42	*
12.	PTT (Problem-1)	PTS1	4.68	3.69	16	*
13.	PTT (Problem-2)	PTS2	2.79	2.48	12	*
14.	PTT (Problem-3)	PTS3	2.04	1.81	8	*
15.	PTT (Problem-4)	PTS4	1.92	2.01	8	*
16.	PTT (Problem-5)	PTS5	1.95	2.90	14	*
17.	PTT (Problem-6)	PTS6	2.04	2.07	9	*
18.	PSTS (Overall)	PSP	19.38	9.43	41	48
19.	PSTS (Problem-1)	PSP1	2.94	2.94	8	8
20.	PSTS (Problem-2)	PSP2	3.64	3.15	8	8
21.	PSTS (Problem-3)	PSP3	3.41	2.46	8	8
22.	PSTS (Problem-4)	PSP4	3.97	2.91	8	8
23.	PSTS (Problem-5)	PSP5	2.43	3.18	8	8
24.	PSTS (Problem-6)	PSP6	2.98	2.83	8	8

* No “max. score possible” due to open-ended questions.

concepts, rules and facts and in translating the problem statements. For the Problem Solving Test for Students (PSTS), Problems 1, 5 and 6 were difficult problems for the majority of the students as the mean scores of these problems were relatively low (less than 40%). Problem 5 was the most difficult problem of the test (30%).

Section A and Section B of the Verbal Knowledge / Intellectual Skill Test (VKIST) which measures the cognitive variables, *Non-Specific but Relevant Knowledge* (NSRK) and *Specific Knowledge* (SK), were generally quite easy for the students as the mean scores for these two sections were quite high (78% and 76% respectively). This indicates that the students, in general, possessed adequate content knowledge in Mole Concept, both the general and specific knowledge related to the six problems.

Correlation analyses

The Pearson correlation coefficients among the five predictor variables and the performance variable for the overall *Problem Solving Performance* (PSP) are shown in Table 6. From Table 6, it is shown that all the predictor variables were moderately and significantly correlated to the performance variable for the *overall Problem Solving Performance* (PSP), except for *Concept Relatedness* (CR), which correlated weakly but significantly. The scores for the six cognitive variables reflected theoretical expectations with respect to relationships among the variables. All the other predictor variables correlated significantly with each other at a confidence level of either 0.01 or 0.05 using two-tailed tests. CR correlated least with the other predictor variables. This trend was also observed to be the case in the two similar studies done earlier (Lee, 1985; Lee *et al.*, 1996). A possible explanation for this observation could be that CR is less reflective in the process of problem solving as compared to *Idea Association* (IA).

TABLE 6: *Correlation between predictor variables and performance variable on the overall problem.*

Variable	PSP	CR	IA	NSRK	SK	PTS
PSP	1.00					
CR	0.17*	1.00				
IA	0.60**	0.06	1.00			
NSRK	0.45**	0.10	0.38**	1.00		
SK	0.46**	0.03	0.22*	0.43**	1.00	
PTS	0.54**	0.04	0.54**	0.44**	0.34**	1.00

*Correlation is significant at the 0.05 confidence level (2-tailed).
**Correlation is significant at the 0.01 confidence level (2-tailed).

Multiple regression analyses

Multiple regression analyses were conducted for the overall problem and for each of the six problems respectively. Four of the five predictor variables significantly contributed to the overall problem-solving performance (Table 9). The four variables are *Concept Relatedness* (CR), *Idea Association* (IA), *Specific Knowledge* (SK) and *Problem Translating Skill* (PTS). Although statistically the *Non-Specific but Relevant Knowledge* (NSRK) variable was not significant in accounting for the overall problem-solving performance, conceptually it was an important background knowledge required for understanding the problems. In addition, NSRK was significantly contributing to problem-solving performance in Problem 3 and Problem 5 (Table 9) respectively. Based on the above reasons, NSRK was not removed from the regression model. As a result, the regression model (Model 1) consisted of five predictor variables. The interaction of all the variables involved was also explored. The variance of the regression model containing the five predictor variables (Model 1) was compared with the variance of the regression model containing the five predictor variables and the interactions of these variables (Model 2) for the overall problem and each of the six problems respectively (Table 7). The results showed that the effect of the interactions was not significant in all the seven problem-solving situations. The best-fit model for problem-solving performance for this study is therefore the additive model of the five predictor variables, excluding the interactions.

TABLE 7: *Variances of Models 1-5.*

Model	Variable	Overall	P-1	P-2	P-3	P-4	P-5	P-6
1	5 Predictor Variables	0.481	0.098	0.169	0.135	0.326	0.379	0.121
2	5 Predictor Variables & Interactions	0.492	0.247	0.220	0.164	0.440	0.451	0.186
3	Component Variables of L & PK	0.456	0.095	0.129	0.134	0.311	0.375	0.116
4	Component Variables of L & PRS	0.442	0.085	0.079	0.083	0.302	0.330	0.097
5	Component Variables of PK & PRS	0.358	0.037	0.128	0.091	0.144	0.167	0.040

Block predictor variables

The variance contributions of the individual block predictor variables to the problem-solving performance were given by the differences in the variances of Model 1 (Table 7) and each of these other models, Models 3, 4 and 5 (Table 7). Model 3 contained the two block predictor variables, namely: *Linkage* (L) and *Prior Knowledge* (PK), while Model 4 contained the two block predictor variables, namely: *Linkage* (L) and *Problem Recognition Skill* (PRS). Model 5, on the other hand, contained the two block predictor variables, namely: *Prior Knowledge* (PK) and *Problem Recognition Skill* (PRS). The variances of problem-solving performance contributed by each of the block predictor variables are shown in Table 8.

For the overall problem, about 48% of the variance of problem-solving performance was accounted for by the five predictor variables (Table 7) and a total of about 19% by the block predictor variables (Table 8). All the three block predictor variables were found to be statistically significant in predicting the overall problem-solving performance, with *Linkage* (L) being the most significant.

TABLE 8: *Variances of problem-solving performance accounted for by the block predictor variables.*

Variable	Overall	P-1	P-2	P-3	P-4	P-5	P-6
PRS	0.025*	0.003	0.040*	0.001	0.015	0.004	0.005
PK	0.039*	0.013	0.090**	0.052	0.024	0.049*	0.024
L	0.123***	0.061*	0.041	0.044	0.182***	0.212***	0.081*

* $p<0.05$
** $p<0.01$
*** $p<0.001$

Predictor variables

The variances of problem-solving performance accounted for by each of the five predictor variables for the overall problem and for each of the six problems were computed in a similar manner as in the case of the block predictor variables. The contributions of the individual predictor variables to the problem-solving performance of the overall problem and the six individual problems are shown in Table 9.

TABLE 9: *Variances of problem-solving performance accounted for by the five individual predictor variables.*

Variable	Overall	P-1	P-2	P-3	P-4	P-5	P-6
PTS	0.025*	0.003	0.040*	0.001	0.015	0.004	0.005
NSRK	0.004	0.000	0.010	0.047*	0.006	0.036*	0.008
SK	0.029*	0.013	0.063**	0.000	0.012	0.004	0.021
CR	0.021*	0.027	0.001	0.014	0.006	0.032*	0.012
IA	0.101***	0.022	0.040*	0.031	0.178***	0.166***	0.070**

* $p<0.05$
** $p<0.01$
*** $p<0.001$

Except for *Non-Specific but Relevant Knowledge* (NSRK), all the other four predictor variables were significant in predicting the problem-solving performance of the overall problem, with *Idea Association* (IA) being the most significant.

Summary of results

This study shows that all the three block predictor variables: *Linkage* (L), *Problem Recognition Skill* (PRS) and *Prior Knowledge* (PK) are significant determining variables, with *Linkage* being the most significant in solving Mole Concept problems at the Grade 9 level. *Problem Recognition Skill* (PRS) and *Prior Knowledge* (PK) are almost equally important, but less influential as compared to *Linkage* variable. In the *Linkage* block variable, both *Idea Association* (IA) and *Concept Relatedness* (CR) are significant, with IA being the dominating variable between the two. In the *Problem Recognition Skill* (PRS) block variable, *Problem Translating Skill* (PTS) is the significant predictor (PTS is the only constituent variable being involved in this study, see "The Study" section). In the *Prior Knowledge* (PK) block variable, *Specific Knowledge* (SK) is the only significant predictor variable between the two constituent variables: SK and NSRK. A part of Table 10 summarises the above results.

INTERPRETATIONS AND DISCUSSION

Cognitive variables

Linkage

The above results seem to imply that the 'linkage' variable was the utmost important predictor for the success of solving Mole Concept problems, ranging between the familiar and partially familiar types. In this study, IA has a greater influence than CR in problem-solving performance and this result is consistent with the earlier studies. Once again, this result confirms the earlier findings that the linkage process which involves eliciting information from the existing cognitive structure by the external cues is more significantly influential than that which involves cross-linking between concepts in the existing cognitive structure.

Prior Knowledge

For the ‘Prior Knowledge’ variable, the results from Table 8 show that the prior knowledge, PK, is significant in predicting the overall problem-solving performance and also the two partially familiar problems, Problem 2 and Problem 5. This supports the findings of the previous studies that PK is an important block predictor variable for solving partially familiar problems.

For the importance of the two constituent predictor variables of PK: the specific knowledge, SK, and the general knowledge, NSRK, Table 9 shows that SK is more significant in predicting the overall problem-solving performance than NSRK. This can probably be explained by the nature of these problems being set for the study. These six problems are all calculation type of problems which require the students to apply specifically certain concepts and intellectual skills (SK) to solve problems. If the students do not have the specific knowledge and skills that are directly related to the particular problem, even though they may have satisfactory general knowledge/skills, they will still be unable to solve the problems. For instance, if a problem requires the use of a balanced chemical equation to determine the ratio of number of moles of reactants and products (SK), a student who knows only the basic concept of mole and how to balance a chemical equation (NSRK) without the above specific knowledge/skills might not be able to solve the problem.

Further more, many students scored reasonably high for both the NSRK (mean is 78%) and SK (mean is 76%), yet many of them were not successful in solving these problems (means of Problem 1 - Problem 6 fall between 30% - 50%). This, again, confirms that one who has content knowledge may not necessarily be a successful problem solver, unless the knowledge has been meaningfully learnt and thus could be effectively used for problem solving (Ausubel, Novak and Hanesian, 1978).

Problem recognition skill

The 'Problem Recognition Skill' variable, or 'Problem Translating Skill', the only constituent variable in this study, is also important in solving Mole Concept problems, but its influential level is not as great as the 'linkage' variable. We can explain this by the familiarity level of the problems. If the students are familiar or partially familiar with the problems, the translation of the statements including the goals of the problems would not be too difficult for them. The success of problem solving in this case would then depend greatly on how relevant and appropriate the information that are being retrieved from the existing cognitive structure is, and how effective the retrieved information and the information from the problem statements are linked so that a solution sequence is possible. It is therefore understandable that 'linkage' variable is a more significant predictor than 'prior knowledge' and 'problem recognition skill ' variables.

Linking to the previous studies

Some similar results emerge from a comparison between this study (Mole Concept Study) and the previous studies (Electrochemistry Studies) (Table 10). The Mole Concept Study involved a mixture of six problems ranging between familiar and partially familiar problems. The Electrochemistry Studies involved the three respective problems of different familiarity (familiar, partially familiar and unfamiliar problems). The importance of block predictor variables in the Mole Concept Study appears to have the same pattern as the results of partially familiar problem in the Electrochemistry Studies. Apart from some slight deviation in the relative importance of the various individual predictor variables in the two topical studies, IA, PTS and SK variables are significant and consistent in their contributions to problem-solving performance across the different topics and levels. The Mole Concept Study confirms the Electrochemistry Studies in that all the cognitive variables, especially IA, PTS and SK are important in solving chemistry problems. Based on the statistical evidence of the three studies, the contribution of CR and NSRK to problem-solving performance varies from one study to another and thus their significance in problem solving is not conclusive at this stage. Nevertheless, the results of the three studies provide consistent evidence of the importance of the cognitive variables, viz., Linkage, Problem Recognition Skill and Prior Knowledge, in solving familiar-partially familiar chemistry problems.

CONCLUSION

The results obtained in this study in comparison with the two previous studies seem to suggest that the difference in topic and level appeared to have little effect on the importance of these variables on problem-solving performance. Solving a mixture of familiar and partially familiar problems, four out of the five cognitive variables investigated, namely: *Concept Relatedness, Idea Association, Specific Knowledge and Problem Translating Skill* (except for *Non-Specific but Relevant Knowledge*), are significant in determining the overall problem-solving performance in Mole Concept. Among them, *Idea Association* is the most important predictor variable. For the successful solutions of a mixture of familiar and

TABLE 10: *Comparison of the results of Mole Concept Study and Electrochemistry Studies.*

Mole Concept Study	Electrochemistry Studies
Problems ranging between familiar and partially familiar problems Overall Results: L > PK ≈ PRS (IA > CR) (SK) (PTS)	Familiar Problem: L > (slightly) PRS (IA) (PTS) Partially Familiar Problem: L > PRS ≈ PK (IA) (*PPSE>PTS) (SK≈NSRK) Unfamiliar Problem: PRS (PTS)

* *PPSE - Prior Problem Solving Experience variable,* a constituent variable of *Problem Recognition Skills* block predictor variable*,* was not included in the Mole-Concept Study.

partially familiar problems, the problem solvers make relevant links between cues from the problem statement and the underlying knowledge base, possess correct specific knowledge and make adequate translation of the problem statements. However, if the problem solvers are unable to make the relevant links they may have difficulty in solving this type of problems even though they may have the required prior knowledge and are able to translate adequately the problem statements.

The above results confirm, once again, the findings of our earlier studies and what other researchers (Ausubel *et al.,* 1978; Reif, 1983; Camocho and Good, 1989; Gabel and Bunce, 1994; Niaz, 1995; Heyworth, 1999) have stressed earlier that an effective problem solving requires the following problem-solving ability and skills:

(1) A good understanding of and meaningfully learnt knowledge;
(2) Appropriate problem-solving procedures which include the re-description of the original problem in a way facilitating the subsequent search for its solution;
(3) Relevant linkages of information between the information of problem statements and the existing cognitive structure

Teachers may emphasise their instruction of problem solving on the above three aspects to improve students' problem-solving performance in Chemistry.

ACKNOWLEDGEMENT: We would like to acknowledge and thank the National Institute of Education, Nanyang Technological University, Singapore, for their financial support for this project (RP 29/95 LL).

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APPENDIX : THE SIX PROBLEMS OF PROBLEM SOLVING TEST FOR STUDENTS

Problem 1: How many moles of the atoms of B (Boron) are present in a sample having 2 x 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 $MgSO_4.xH_2O$, 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 $MgSO_4.xH_2O$.

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 :

$$X_2 \quad + \quad 2NaY \quad \rightarrow \quad Y_2 \quad + \quad 2NaX$$

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.

$$4NH_3(g) \quad + \quad 5O_2(g) \quad \rightarrow \quad 4NO(g) \quad + \quad 6H_2O(l)$$

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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