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COMPARISON OF AUSTRALIAN AND SINGAPOREAN STUDIES ON PROBLEM SOLVING VARIABLES IN CHEMISTRY*

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ABSTRACT

The development in students of the ability and skills to solve problems is of current interest and concern in education in general, and in science education in particular. What are the most important problem-solving skills that should be taught in science lessons for more effective problem solving?

This is a revisited study on the role of cognitive variables viz., concept relatedness, idea association, problem translating skill, prior problem-solving experience, specific knowledge and relevant but non-specific knowledge in problem-solving performance in Chemistry. The earlier study was conducted in Australia. Two hundred and seventy-nine Pre-University Two Chemistry students from six Singapore junior colleges were involved in this second study. Six testing instruments, two traditional types and four non-traditional types, were used as in the previous study to measure these variables. This paper presents the findings of the Singaporean study on the relationships between the cognitive variables and problem solving performance in solving three electrochemistry problems of different degrees of familiarity. The findings are then compared with the Australian study. The implication of the study for teaching and learning problem solving have been addressed.

Key Words: Problem Solving, Science Education, Comparative Study

Introduction

An analysis of literature on problem solving in science education led to a number of theoretical models of problem solving. One part of these models concerned identifying a number of cognitive variables that are postulated to affect the problem solving performance. Six such cognitive variables were identified and defined:- *Specific Knowledge, Non-Specific but Relevant Knowledge, Concept Relatedness, Idea Association, Problem Translating Skill, and Prior Problem Solving Experience* (Lee, 1985).

Specific Knowledge is the particular rules or facts which are directly related to or required for solving the problems and *Non-Specific but Relevant Knowledge is* the relevant rules or facts which are generally related to the subject area of the problems. These two cognitive variables provide measures of the capacity of the solver's memory store, they are blocked as a *Prior Knowledge* variable (PK). *Concept Relatedness* is a measure of the relatedness between concepts that are involved in problem solving and *Idea Association* measures the ability to associate ideas, concepts, words, diagrams or equations through the use of cues which occur in the statements of the problems. Since these two variables concern linkage measuring the degree of association of the information storage, they are blocked as a *Linkage* variable (L). *Problem Translating Skill* measures the capacity to comprehend, analyze, interpret and define a given problem and *Prior Problem Solving Experience* 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* variable (PRS). Table 1 summarizes the three blocks of problem solving variables and their constituent variables.

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Table 1: Determining Variables for Problem Solving

Block Variable	Constituent 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 previous study conducted by Lee (1985) on cognitive variables influencing problem solving performance on electrochemistry involved 214 Grade 12 chemistry students from six high schools in Australia. The study has proved that problem solving performance of solving chemistry problems was related to the above-mentioned six cognitive variables. The variables had different effect on problem solving performance in problems that differed in terms of familiarity.

The purpose of this paper is to present some findings of a second study, conducted in Singapore, on the cognitive variables of problem solving in chemistry. These findings are then compared with the Australian study.

Methodology

Variables and Instruments

The same topic, electrochemistry, at the pre-university level and the same six instruments used in the previous study (Lee, 1985) were again used in this Singaporean study. The six cognitive variables mentioned above, the predictor variables, were measured by 5 instruments. The dependent variable (or performance variable) was measured by a problem solving test, *Problem Solving Test for Students* (PSTS). The six instruments are listed in Table 2; two were traditional types of tests: multiple-choice questions and problem solving test, and four were non-traditional, open-ended types of tests.

Table 2: Problem-Solving Variables and Instruments

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

The test of PSTS consisted of 3 problems. Problem-1 was a familiar-type problem which concerned the strength of oxidants and reductants in the galvanic cells. Problem-2 was a partially-familiar problem which concerned the prediction of redox reactions using E^{O} values. Problem-3 was an unfamiliar-type of problem which required students to use same sort of knowledge of electrochemistry as in Problems 1 and 2 to reason about an unstable compound. There were four measures of the performance variable: problem solving performance for Problem-1 (PSP1); for Problem-2 (PSP2); for Problem-3 (PSP3); and, overall, for Problems 1, 2 and 3 (PSP), the sum of PSP1, PSP2 and PSP3.

Administration

The study involved 279 Pre-University Two Chemistry students from six junior colleges. The six instruments were administered to the students after the topic of electrochemistry had been taught in two tutorial periods (50 minutes each period). The sequence of administering the tests was the same as in the Australian study: Concept Relatedness Test, Association Test, Verbal Knowledge / Intellectual Skill Test in the first session; Problem Translating Test, Problem Solving Test for Students and Prior Problem Solving Experience Probe in the second session.

Results

The data collected in Singapore were analyzed and some of it are presented in this paper together with the results of the Australian study for comparisons of the following aspects:

- correlation analyses
- multiple regression analyses

Correlation Analyses

The correlations between the block predictor variables and their constituent variables and the performance variable for Problem-1, Problem-2, Problem-3 and PSP the overall problem, were computed. The correlations for PSP and the constituent variables are shown in Table 3 together with the Australian values.

Concept Relatedness was correlated lowly with PSP for the Singaporean study but it was quite significantly correlated for the Australian study. In both studies, *Concept Relatedness* correlated least with the other constituent variables, and *Non-Specific but Relevant Knowledge* also correlated lowly with *Prior Problem Solving Experience*. The correlations between the other individual predictor variables were generally higher for the Singaporean study than the Australian study.

Multiple Regression Analyses

Multiple regression analyses were conducted for the overall problem and for each of the three problems separately. Five out of the six variables significantly contributed to the problem solving performance of the Singaporean students instead of all six variables in the Australian study. The five variables are *Idea Association, Non-Specific but Relevant Knowledge, Specific Knowledge, Problem Translating Skill,* and *Prior Problem Solving Experience*. The *Concept Relatedness* variable was insignificant to the problem solving performance for the Singaporean students. The interaction of the variables involved was explored in the process of developing the best regression model. The variance of the regression model containing the five predictor variables (Model 1) was compared with the variance of regression model containing the five predictor variables and the interactions of these variables

(Model 2) for the four measures of problem solving performance (Table 4). The results show that the effect of the interactions was insignificant in all the four problem solving situations. The best-fit model for problem solving performance for the Singaporean study was the additive model of the five constituent predictor variables excluding the variable of *Concept Relatedness*. The best-fit model of problem solving performance for the Australian study consisted of all the six constituent predictor variables.

Table 3: Correlations between Predictor and Performance Variables on Overall Problem of the Australian (in brackets) and Singapore Studies

Variable	PSP	CR	IA	NSRK	SK	PTS	PPSE
PSP	1.0 (1.0)						
CR	0.05 (0.24)	1.0 (1.0)					
IA	0.59 (0.48)	0.19 (0.09)	1.0 (1.0)				
NSRK	0.42 (0.32)	0.02 (0.04)	0.49 (0.35)	1.0 (1.0)			
SK	0.52 (0.29)	0.09 (0.05)	0.51 (0.34)	0.48 (0.29)	1.0 (1.0)		
PTS	0.45 (0.42)	0.07 (0.05)	0.55 (0.38)	0.40 (0.21)	0.43 (0.20)	1.0 (1.0)	
PPSE	0.20 (0.40)	-0.02 (0.12)	0.23 (0.28)	0.09 (0.04)	0.24 (0.17)	0.18 (0.28)	1.0 (1.0)

Table 4: Variances of the Five Models

Model	Variable	Overall	Problem-1	Problem-2	Problem-3
1	5 Predictor Variables (excluding CR)	0.425	0.122	0.452	0.225
2	5 Predictor Variables & Interactions	0.442	0.146	0.469	0.262
3	Component Variables of L & PK	0.417	0.093	0.417	0.185
4	Component Variables of L & PRS	0.373	0.105	0.423	0.155
5	Component Variables of PK & PRS	0.350	0.101	0.363	0.218

Table 5 shows the variance of the problem solving performance on the four measures accountered for by the six or five variables in the two studies. The variances of the overall problem solving performance for both countries were quite close to each other, about 40-43%.

For the respective problems, the variances of problem solving performance of Singaporean students are reasonably close to the variances of the Australian study. This implies that the contribution of these variables to problem solving performance was fairly consistent across both countries.

Table 5: Comparisons of Australian and Singaporean Studies in Variances of Problem Solving Performace Accounted for by the Cognitive Variables

Measure	Variance R^2	
	Australian Study*	Singaporean Study#
Overall	0.399	0.425
Problem-1	0.178	0.122
Problem-2	0.366	0.452
Problem-3	0.255	0.225

* Regression involving six predictor variables.

\# Regression involving five predictor variables (all the variables except *Concept Relatedness*).

Block Predictor Variables

The contribution of the three respective block predictor variables to problem solving performance was worked out in the following way. Regression analyses were carried out on Models 3, 4 and 5 respectively. Model 3 contains the two block variables of *Linkage (L)* and *Prior Knowledge (PK)*. Model 4 contains those of *Linkage (L)* and *Problem Recognition Skill (PRS)*. Model 5 contains the component variables of *Prior Knowledge (PK)* and *Problem Recognition Skill (PRS)*. For the Singaporean study, the *Linkage* variable consisted only of *Idea Association* variable because *Concept Relatedness* variable was insignificant to the problem solving performance as discussed earlier. The variances of Models 3, 4 and 5 are shown in Table 4. The changes between the variances of Model 1 and each of these other models (Models 3, 4 and 5) were the contribution of the three respective block predictor variables to the problem solving performance. Table 6 shows the variances of problem solving performance contributed by the block predictors of the two studies.

Table 6: Variances of Problem Solving Performance Accounted for by the Block Predictor Variables

Block Variable	Problem 1		Problem 2		Problem 3	
	Aus Study	Sing Study	Aus Study	Sing Study	Aus Study	Sing Study
PRS	0.035*	0.029*	0.074**	0.035**	0.104**	0.040**
PK	0.024	0.017	0.050**	0.029**	0.012	0.070**
L	0.052**	0.021**	0.069**	0.089**	0.024	0.007

** $P<0.01$

* $P<0.05$

For Problem-1, about 12% of the variance of problem solving performance was accounted for by the five predictor variables (Table 5) and about 7% by the block predictor variables (Table 6). Similar to the Australian study *Problem Recognition Skill* and *Linkage* were both important in the prediction of problem solving performance on the familiar problem. Prior Knowledge was not statistically supported as a significant predictor for problem solving performance.

For Problem-2, about 45% of the variance of problem solving performance was accounted for by the five predictor variables (Table 5) and 15% by the block predictors (Table 6). All the three block predictor variables: *Linkage, Prior Knowledge,* and *Problem Recognition Skill* were significant block predictors in solving partially familiar problems as in the Australian study.

In the case of Problem-3, about 23% of the variance of problem solving performance was accounted for by the five predictor variables (Table 5) and about 12% by the block predictor variables (Table 6). *Problem Recognition Skill* and *Prior Knowledge* were both important predictors of the problem solving performance for the Singaporean study, while Problem Recognition Skill was the dominant block predictor of the problem solving performance for the Australian study.

Predictor Variables

The contribution of each of the five predictor variables to the problem solving performance of the three respective problems was worked out in the following way. Five multiple regression analyses for each of the three problems were conducted in such a way that each time one of the predictor variables was removed from Model 1 (Table 4). The change in the value of variance that was obtained in each case is the variance of problem solving performance accounted for by the absent predictor variable. Table 7 shows the comparisons between the contributions of each predictor variable to the problem solving performance of Problem-1, Problem-2 and Problem-3 in the two studies.

Table 7: Variance of Problem Solving Performance Contributed by Individual Predictor Variable on the Three Problems in the Two Studies

Variable	Problem 1		Problem 2		Problem 3	
	Aus Study	Sing Study	Aus Study	Sing Study	Aus Study	Sing Study
PTS	0.024*	0.014*	0.021*	0.010*	0.041**	0.030**
PPSE	0.010	0.015*	0.036**	0.021**	0.044**	0.007
NSRK	0.010	0.001	0.020*	0.011*	0.012	0.003
SK	0.008	0.011	0.017*	0.009*	0.001	0.045**
CR	0.025*	-	0.012	-	0.013	-
IA	0.027*	0.020*	0.055**	0.089**	0.009	0.007

** $P < 0.01$
* $P < 0.05$

For Problem-1, the two constituent predictor variables, i.e. *Problem Translating Skill* and *Idea Association*, consistently and significantly contributed to the problem solving performance in both studies. As mentioned earlier, *Concept Relatedness* was not significant to Singaporean students in their problem solving, while it was significant to the Australian students. *Prior Problem Solving Experience* significantly contributed to the problem solving for the Singaporean students because Problem-1 was not such a familiar problem to them.

For Problem-2, the partially familiar problem, as in the Australian study, five predictor variables, *Problem Translating Skill, Prior Problem Solving Experience, Non-Specific but Relevant Knowledge, Specific Knowledge,* and *Idea Association*, significantly contributed to the

problem solving performance of Singaporean students. Among the five variables, *Idea Association* was the most influential predictor in the two studies.

For Problem-3, the unfamiliar problem, *Problem Translating Skill* consistently showed up as a significant variable in both studies. *Specific Knowledge* significantly contributed to the problem solving performance for Singaporean students. On the other hand, *Prior Problem Solving Experience* was also significant for predicting problem solving performance of Australian students.

Interpretations

In the comparison of the two studies undertaken in Australia and Singapore of different cultures and systems of education, there was consistent evidence of the importance of the cognitive variables to problem solving and their influence in the different types of problems. *Prior knowledge, problem recognition skill* and *linkage* were all important variables in solving electrochemistry problems in particular and chemistry problems in general. The results of the studies imply that the problem solvers must have the right rules and facts in their minds as the primary requirement for securing the correct answer. The next requirement for a successful problem solving will then be determined by the right operations of problem recognition and linkage between information.

Problem recognition skill was a combined measure of both problem translation and prior experience in solving the same kind of problems. The accuracy of translating the statements including the goals of the problems was specifically important in solving all types of problems. The misinterpretation of any essential parts of the statements did not likely lead to a correct solution. The prior experience in solving a problem is also important, because with the experience the problem solvers were more confident in generating meanings of the statements and identifying the ways to achieve the goals or subgoals for the solution.

Linkage between the external cues and the relevant information (rules or facts) available in the existing cognitive structure was more significant than the concept relatedness between concepts in the existing cognitive structure for problem solving. This kind of linkage - idea association was significant to problem solving particularly after the accurate translation of the statements was made.

For the *prior knowledge*, the studies also imply that problem solvers who have adequate rules or facts are not necessarily good at problem solving. This can be illustrated by the fact that many students in the studies had good scores on the prior knowledge test (VKIST). However, many students failed their problem solving test (PSTS), especially the Singaporean students on Problem-1. The students had the adequate knowledge required for solving these three problems but were unable to translate correctly the statements or/and make relevant links between the information for a correct solution.

On the different types of problems, the cognitive variables contributed differently to the problem solving performance. The significant contribution of block predictor variables and their constituent predictor variables in the problem solving performance on the three problems of different degrees of familiarity which were agreeable between the two studies are summarized in Table 8.

For solving a familiar problem, prior knowledge became less crucial in problem solving because the students should have known quite well the knowledge required for the solution. The success in solving the familiar problem was then very much dependent on the accurate translation of the problem statement and adequate linking of information.

In the case of a partially familiar problem, students very often were not certain about the prior knowledge, the meanings of the statement and how to associate the information together for solving the problem. This is why all the five variables were responsible for the solution of this kind of problems. In addition, the linking of the translations to the rules, algorithms or ideas (idea association) turned out to be more significant than the other variables in solving a partially familiar problem (Table 7). This is not surprising as without the relevant linkage between the appropriate rules and relevant components of translation of problem statement, there was likely to be a mis-match of information, which was definitely not helpful in solving the problem.

To solve an unfamiliar problem with statement that students had never come across before, the translation of the statement was crucial. If the students did not know what the problem was asking for, they would be unable to solve the problem even though they might have good linking skill and adequate prior knowledge.

Table 8: Summary of Regression Analyses Results of Australian and Singaporean Studies

Type of Problem	Important Predictors	
	Block	Individual
Problem-1 (Familiar)	Linkage	Idea Association
	Problem Recognition Skill	Problem Translating Skill
Problem-2 (Partially Familiar)	Linkage	Idea Association
	Problem Recognition Skill	Problem Translating Skill, Prior Problem Solving Experience
	Prior Knowledge	Non-Specific but Relevant Knowledge, Specific Knowledge
Problem-3 (Unfamiliar)	Problem Recognition Skill	Problem Translating Skill

Implication for Teaching and Learning Problem Solving

The effective instruction of problem solving requires teachers to teach relevant knowledge in a manner that encourages its meaningful learning, to teach problem solving skills and also to provide opportunities for practice at solving problems. As a result of the two studies, it was found that apart from prior knowledge, linkage and problem recognition skills are both important skills in problem solving. Training in linkage and problem recognition skills for improving problem solving performance is therefore necessary. The variables of problem translating skill, idea association and concept relatedness could be taught and emphasized during the teaching of subject matter or the teaching of problem solving. Learning of these variables would reinforce the learning of relevant knowledge in a meaningful way so that knowledge becomes organized into the learner's cognitive structure as a procedural network for problem solving.

Learning of translation skills should be considerably emphasized by teachers by dwelling on the significance of the problem statement and its component parts. Practice of problem translation through class activities or home exercises can be organized as part of teaching strategies. The learning of linkage (idea association and concept relatedness) through association exercises, namely word association (Gunstone, 1980) and idea association (Lee, 1985), is very useful for creating a meaningful learning situation in both teaching situations, i.e. teaching knowledge and problem solving.

References

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