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Source	*ERA-AME-AMIC Joint Conference, Singapore, 4-6 September 2000*
Organised by	Educational Research Association of Singapore (ERAS)

TEACHING PROBLEM-SOLVING SKILLS IN CHEMISTRY

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Abstract: One of the main goals of science educators is to develop in their students the ability to solve problems in science. Recent research has found that students face a number of difficulties in this area. The main difficulties that the students have are that many of them do not understand the concepts involved in the problems and they are unable to apply the conceptual knowledge in solving the problems. Previous studies done indicated that linkage and problem translating skills are significant determining variables of problem-solving performance. This study attempted to examine the feasibility of explicitly teaching students these problem-solving skills and the effects of these skills on students' problem-solving performance. One hundred and fifteen secondary three pure chemistry students from three classes in the express stream were involved in this study. The topic for the study is Mole Concept. The traditional method (control) and the explicit teaching of linkage and problem translating skills (treatment) for teaching problem solving were respectively conducted. This paper reports on some of the findings of the study. The paper will also discuss the implications of the findings for teaching problem solving in chemistry.

Introduction

Research examining the cognitive development of students and its relevance to instruction has been extensive. During the last two decades, there has been a great deal of work in the study of cognitive processes in students' learning of science. Much of this research is concerned with students' understanding of natural phenomena and students' cognitive structure and conceptual learning (Novak, 1985; Novak & Musonda, 1991; White & Gunstone, 1992; Bell, 1993; Fensham, Gunstone & White, 1994). The research involves studying fundamental issues (e.g. Children's views about scientific phenomena and how students learn) and practical issues in relation to instruction (e.g. how students' concept can be changed).

A number of studies done during the last two decades tried to bridge the gaps between a cognitive study of learners' science knowledge and problem solving. These studies showed that many students either did not understand the chemical concepts involved in chemistry problems or were unable to apply conceptual knowledge in solving the problems (e.g. Lee, 1985; Nurrenbern and Pickering, 1987; Sumfleth, 1988; Niaz, 1995; Lee, Goh, Chia and Chin, 1996). Gabel and Bunce (1994), in their review of research studies on problem solving in chemistry for the past twelve years, concluded that students solve the problems relying primarily on the use of algorithms rather than the meaning of the underlying concepts.

Lee (1985) did a study in Australia to investigate cognitive variables that affect problem-solving performance in electrochemistry. She found that successful problem solving is dependent on several important cognitive variables which can be blocked as 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). These block variables consist of cognitive variables and it was also found that the influence of these cognitive variables on success of problem-solving varies with the familiarity of the problem.

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 are different (Lee, Goh, Chia & Chin, 1996). The findings of the two studies (Lee, 1985; Lee, Goh, Chia & Chin, 1996) are consistent and able to link problem-solving success to adequate translation of problem statement, relevant linkage between problem statement and knowledge, and correctness of prior knowledge retrieved. From this, Lee (Lee, et al, 1996) concluded that acquisition of knowledge alone does not guarantee problem-solving success. Certain problem solving skills or cognitive strategies must be learned. Unfortunately, these problem solving skills (e.g. problem translating skills and linkage skills) are not explicitly taught in schools.

In this study, an attempt is made to teach some of these problem-solving skills, namely, linkage skills and problem translating skill, to the students. The main objectives of this study are:

(1) to improve the problem-solving performance among students.
(2) to equip students with the above-mentioned problem-solving skills.
(3) to improve students knowledge in stoichiometry and mole concept.

Method

Subjects

This study involved a total of 115 secondary three pure chemistry students in the express stream 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 age ranging between thirteen and sixteen years. The students who qualified to study in the express stream at secondary level must have obtained a good pass in the Primary School Leaving Examination. Three middle-range intact classes of average ability were chosen to form the control group and the two treatment groups.

Research design

A quasi-experimental design was adopted since random assignment of subjects was not possible as intact classes were used. The subjects were taken from three intact classes so as not to upset the normal school routine and organisation. The non-equivalent control-group design (Campbell & Stanley, 1963) was used. The design is shown below:

O_1 x O_4

O_2 x O_5

O_3 * O_6

Note:
$O_1 \equiv O_2$ (repeat measure)
$O_4 \equiv O_5$ (repeat measure)

Figure 1: The Research Design

In this design,

- x represents the teaching of content knowledge and its application on problem solving with the incorporation of teaching linkage and problem translation skills explicitly (Teaching Strategy I).
- * represents the teaching of content knowledge and its application on problem solving without emphasising the teaching of linkage and problem translation skills (Teaching Strategy II).
- O_1 represents the pre-test used to measure the problem solving performance of students in Group 1 (Treatment).
- O_2 represents the pre-test used to measure the problem solving performance of students in Group 2 (Treatment).
- O_3 represents the pre-test used to measure the problem solving performance of students in Group 3 (Control).
- O_4 represents the post-test used to measure the problem solving performance of students in Group 1 (Treatment).
- O_5 represents the post-test used to measure the problem solving performance of students in Group 2 (Treatment).
- O_6 represents the post-test used to measure the problem solving performance of students in Group 3 (Control).

Two groups of students were randomly selected for treatment in this study. The reason of having two groups of students undergoing the same treatment is that it could reinforce any conclusion made based on the outcome of the treatment given. The same instrument was used for the pre-test and the post-test for all the groups. Scores of the pre-test served as a baseline for comparison to reduce any differences in the abilities of the students in the different groups, since only their gain scores were used to determine whether there was any effect due to the treatment.

Experimental procedure

The topic that was taught in this study was Mole Concept. This topic was part of the 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 (the researcher) taught all the three classes so as to minimise the individual differences in teaching styles and in the delivery of course content for the three groups. Students in all the three groups were instructed identically except for the teaching of linkage skills and problem translating skills. While the researcher taught the linkage and problem translating skills for solving problems to the treatment groups, he used traditional method (supply solutions to the problems) to teach problem solving to the control group on the same examples.

The experiment was carried out over a time frame of five weeks, excluding the administration of the pre-test and post-test. The pre-test and post-test were administered just before and after the topic was taught respectively. Each class had four periods of chemistry theory lesson per week and each period lasted thirty-five minutes.

Teaching Strategy I

This teaching strategy was similar to the traditional teaching strategy (Teaching Strategy II) except that the training of the students in linkage and problem translating skills was incorporated into the teaching of content knowledge of Mole Concept and its application on problem solving. The total time spent on teaching the topic of Mole Concept using Teaching Strategy I was identical to that in Teaching Strategy II. This was possible as the content knowledge taught and the examples used to illustrate the concepts taught for Teaching Strategy I were the same as that for Teaching Strategy II. However, in Teaching Strategy I, the examples were converted into worksheets that were used to train the students in linkage and problem translating skills. Students were taught linkage skills through working with them on the word association and idea association activities.

For the word association activity, 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. 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.

For the idea association activity, students were asked to associate each key word or problem stem found in the worksheets to any information from their minds and put the associative responses in writing on the worksheets. They were given about one minute for each key word and about three minutes for each problem stem to complete the assigned task.

As for the teaching of problem translating skills, 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 re-state the problem statements into their own words, and to set the steps for achieving the solution. They were given about ten minutes to complete this task for each problem.

A summary of the total number of each type of worksheet given to the students and the time spent on teaching each skill for the whole duration of the treatment is given in Table 1.

Table 1
Summary of the total number of each type of worksheet used and the total time spent in training each skill

Type of problem-solving skill	Total no. of worksheets	Total time spent (min)
word association	7	60
idea association	7	70
problem translating skill	15	130

The examples used and the content knowledge taught were the same as that for Teaching Strategy II. Group 1 and Group 2 (Treatment Groups) were taught using this strategy.

Teaching Strategy II

Teaching Strategy II was generally termed the traditional teaching strategy, which focused mainly on the teaching of content knowledge of Mole Concept and its application on problem solving. It was basically teacher-centred, although sometimes students were asked to show their solutions to the examples on the whiteboard. Linkage and problem translating skills were not taught and the learning of these problem-solving skills was totally left to chance. Group 3 (Control Group) was taught using this strategy.

Instrument

The instrument used in this study was Problem Solving Test for Students (PSTS). It consisted of six problems on Mole Concept and included both familiar and partial familiar problems. Familiar problems refer to problems which are similar to the questions that have been set in O-Level examinations or used in the textbooks while partial familiar problems refer to problems which are in part similar to the questions having been set in O-Level examinations or used in the textbooks. The Problem Solving Test for Students (PSTS) was designed to measure the Problem Solving Performance (PSP) (dependent variable) of students which is the performance (score) of problem solving on the six problems of the Problem Solving Test for Students (PSTS).

The format of the instrument was based on a similar study on junior college students' problem solving performance in electrochemistry done by Lee et al. (1996). The content of the items in the instrument was based on the key concepts in the topic on Mole Concept as required by the GCE 'O' Level Syllabus for Chemistry.

Administration of the instrument

The Problem Solving Test for Students (PSTS) was administered to the students in a single period before and after the teaching of the topic Mole Concept as pre-test and post-test respectively. The time allocated for administering the instrument was 30 minutes.

Results and Discussion

A statistical hypothesis was formulated to determine whether there was any significant difference in the problem-solving performance among students who were taught linkage and problem translating skills and those who were not taught in the topic of Mole Concept. The gain scores, which are the differences between the post-test and pre-test scores, for every student in each group were used for the data analysis. This is to remove any initial differences between the students from different groups as only the “improvement” of the students after the treatment are compared and not their absolute scores. One-way analysis of variance (ANOVA) on the gain scores was employed to assess the significance of the differences in terms of Problem-Solving Performance (PSP) among the three groups of students. (Groups 1 and 2 were the treatment groups and Group 3 was the control group.) The treatment given to Groups 1 and 2 involved the teaching of content knowledge of Mole Concept and its application on problem solving together with the teaching of linkage and problem translating skills. The teaching method given to the control group, Group 3, focused mainly on the teaching of content knowledge of Mole Concept and its application on problem solving without explicitly emphasising the teaching of linkage and problem translating skills to the students.

The means and standard deviations of the gain scores for PSTS in each group are shown in Table 2.

Table 2
Means and standard deviations of the gain scores for Problem Solving Test for Students (PSTS)

Group	N	Mean	S.D.
1	40	12.3	7.8
2	37	12.9	8.5
3	36	7.5	7.5

The F-ratio obtained from a one-way analysis of variance on the gain scores for PSTS was 5.1, significant at 0.01 confidence level. Thus, the null hypothesis was rejected and at least one out of the three comparisons between pairs of mean gain scores for PSTS was significant. Post Hoc comparisons using the Scheffé’s Test were then carried out to identify where the difference or differences lie.

The differences between the mean gain scores of Group 1 and Group 3 as well as that of Group 2 and Group 3 were both significant at the 0.05 confidence level. The risk of type I error in claiming these differences to be true was less than 0.05 per experiment, using two-tailed tests. This result showed that the increase in the problem-solving performance scores of both treatment groups (Groups 1 and 2) were significant as compared to the control group (Group 3). This implied that the treatment had an effect on the problem-solving performance of the students.

Both treatment groups who were taught linkage 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. The mean gain scores of the students in these two groups were about five marks more than that of the students in the control group. Thus, in general, it was found that the explicit teaching of linkage and problem translating skills does enhance the problem-solving performance.

The feasibility of explicitly teaching students problem-solving skills, namely: linkage skills and problem translating skill, are summarised as follows:

Linkage skills

The researcher found that linkage skills were not difficult to teach. It can be done through completing worksheets. However, a little planning is necessary, for example, to identify the key concepts of the topic before the topic is taught to the class or selecting appropriate problems that can be used to teach content knowledge as well as linkage skills. This is important because a substantial amount of curriculum time will be saved. Once that is done, worksheets can be designed easily. Completing the worksheets within a time limit forces the students to concentrate and think, thus to integrate new knowledge with their existing cognitive structure. The discussion that follows every worksheet after its completion also helps the students to clarify any doubts they have. Students generally found linking ideas easier compared to linking concepts. This is probably because the former is less restrictive as it includes many different forms of association including words, diagrams and equations.

Problem translating skill

This skill can be easily incorporated into the teaching of the topic as it can be applied to any problem in that topic. 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 re-state the problem statements into their own words, and to set the steps for achieving the solution. Similar to the case of teaching linkage skills, the same problems for teaching content knowledge can also be used for training this skill. Curriculum time is therefore optimised in this way as the students are not asked to do something extra but to put down in writing what normally would just flash across their minds when they attempt to solve a given problem. This enables them to focus on the key concepts involved in the problems and thereby to increase their chances of solving successfully the problems later. Worksheets are designed to include one problem in one worksheet. A minor hiccup faced in the study was that some students initially tried to solve the problems instead of stating the steps they would take to solve the problems. This was however overcome after some practice. Hence, to teach problem translating skill in the classroom situation is feasible.

Implications for teaching problem solving in chemistry

The results obtained in this study seems to imply that the learning of problem-solving skills should not be left to chance. Students should be taught problem-solving skills explicitly and ample opportunities should be given to students to practise the skills if the acquisition of these problem-solving skills is expected to take place in the classroom environment. Furthermore, for the teaching of the skills to be effective, it is suggested to use a longer training period and properly trained teachers. 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 skills.

Based on the nature of Chemistry, it is obvious that the acquisition of the problem-solving skills can only be meaningful if they are applicable to actual real life situation. As a result, teachers should also use real problems as examples for demonstrating the application of the skills in problem solving. In this way, students will find the skills more practical and thus be more motivated to learn them.

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

Conclusion

Despite its limitations, the results of this study have shown that the teaching of linkage and problem translating skills enhance problem-solving performance of students. The teaching of these skills is feasible and practicable in the classroom environment. It is therefore believed that this study is important in adding to the body of knowledge in the area of problem solving. It is thus hoped that the findings of this study will be of practical value to science educators and practitioners in schools.

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