# AN INTERVENTION PROGRAMME OF TEACHING PROBLEM SOLVING STRATEGIES IN SINGAPORE SCHOOLS: PRELIMINARY CASE STUDIES

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ABSTRACT

An intervention programme on the teaching of problem solving skills, consisting of the think-aloud and general problem solving strategies, was introduced as part of a chemistry in-service course to a group of Singapore teachers. Feedback from the teacher-participants on the programme and its usefulness to learning problem solving skills was favourable. In an attempt to investigate the effect of this programme on students' problem solving skills, case studies were undertaken a year later. This paper reports the findings of four case studies on the implementation of the intervention programme to chemistry students and evaluation of the students' problem solving performance and behaviour before and after the intervention. Four teachers, two from secondary schools (ages of students were 14-15) and two from junior colleges (ages of students were 16-17), were involved in the case studies. The methods of evaluation of the students' problem solving performance and behaviour varied among the four teachers. The quantitative perspective was emphasized by one; the qualitative was by the other three. The implications of the case studies for the teaching and learning of problem solving have been discussed.

## Introduction

In class, the teacher is responsible for providing the learning experiences to the students. Thus the student's ability to develop the problem solving skills depends largely on the teacher's instructions. Teaching which generates inert knowledge, i.e. knowledge that may be recalled but not used, results in an inability to transfer skills and ideas from one context to another (Lipman, 1987). It has been found that achievement in science courses can be multiplied when educationally disadvantaged students are taught problem solving together with the subject matter (Carmichael, Bauer and Robinson, 1987). Pestel (1993) in his research on the teaching of problem solving found that the conventional teaching methods which rely predominantly on presenting information, showing prototypical examples of workout problems and providing students with practice in solving similiar kind of problems do not help to develop the students' problem solving skills. This type of teaching allows students to remain passive. Many students assume that "you either know the answer to a question or you do not", and that if they do not know the answer, there is nothing they can do about it (Lochhead, 1985). This coincides with Reif's report (1983) that the students are more concerned with the answer than with the process involved in solving the problems.

Lee (1986) investigated the teaching approaches used by the Australian teachers in teaching problem solving and found that the teachers predominantly concentrated on presenting information while students witnessed their teachers' demonstration of using rules and algorithms for solution to problems. The teachers spent very little time on teaching problem solving skills such as analyzing the problem statements or discussing strategies pertaining to solving science problems. In Garrett's review paper (1986) on problem solving in science education, many researchers have suggested that problem solving can be substantially improved if the task is approached more scientifically and systematically. More emphasis should be

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placed on the important aspect, namely, the systematic organization of the thinking process required for problem solving. A model of problem solving employing Whimbey's think-aloud approach (Whimbey, 1984; Woods, 1985a) can be used to develop the awareness of process skills while solving a problem. The approach involves students working in pairs with each person assigned a specific task; each student works the problem with a partner who does not directly participate in the problem solving but forces the problem solver to verbalise all thought processes.

At Xavier University of Louisiana, the emphasis on problem solving in general chemistry is one component that has helped to assist students reach expected levels of performance. An adaptation of the "Whimbey method" of teaching problem solving is used whereby students work in trio and focused on careful, methodical work in which all the steps are clearly articulated and constantly checked for accuracy (Carmichael, Bauer and Robinson, 1987). As for Pestel (1993), during a preliminary evaluation of the teaching strategy, one course was taught using Whimbey's think-aloud approach and another using the conventional approach to problem solving. The outcome was that although the class under the think-aloud approach got fewer problems completely right, they also got fewer problems completely wrong. The decrease in the percentage of problems answered correctly by the class taught using the think-aloud method might be a result either of fewer students memorising templates or of students relying on problem solving skills not only to begin the problem but to solve the problem itself.

If teachers want to do something more effective in developing students' problem solving skills, a more systematic and specific strategy such as breaking the skills into parts, identifying observable objectives and providing feedback to show fulfilment of those objectives can be

introduced. A general problem solving strategy can be specifically taught to students to help them to know how to start, where to start, how to analyze and how to proceed with the solution when given a problem. The McMaster 6-step strategy (Wood, 1985b) consists of 6 stages of solving processes which include (1) Read/I want to and I can, (2) Define, (3) Explore, (4) Plan, (5) Do it, and (6) Look Back, that can be used in the classroom instruction of problem solving. Whimbey's think-aloud approach was recommended for introducing this strategy in class (Woods, 1985b). The students are expected to identify which of the six stages in the strategy they are at while using the think-aloud approach to solve problems.

Lee (1993) introduced the Whimbey think-aloud strategy and McMaster 6-step strategy (general problem solving strategy) through the Whimbey method to the in-service teachers in Singapore. The teaching of these two strategies was conducted in two workshop sessions. The think-aloud strategy was taught in the first session and the general problem solving strategy in the second. Most of the teachers recognise the usefulness and importance of the two problem solving strategies in developing problem solving skills. They consider the think-aloud strategy a good technique for tapping the thinking in one's mind and that it is useful to have students solve aloud unfamiliar problems. At the same time, the general problem solving strategy can provide students with a sense of overall strategy to solve science problems. In an attempt to investigate the effect of these two strategies on students' problem solving skills, a follow-up preliminary cross-case study was undertaken.

This paper is a report of this cross-case study on the effect of an intervention programme on the students' problem solving performance and skills in solving chemistry problems. This intervention programme

consists of the Whimbey think-aloud strategy and McMaster general problem solving strategy.

## Methodology

This study involved four teachers, two from two secondary schools and two from two junior colleges in Singapore. The involvement of these four teachers was on a voluntary basis upon invitation. These four teachers are addressed as Mrs. Koh (Case 1), Mr. Low (Case 2), Miss Lim (Case 3) and Miss Loh (Case 4) in this paper. Mrs. Koh and Mr. Low taught the Chemistry components of the Combined Science subject in the secondary schools. The subject of Combined Science comprises of two sciences, e.g. Chemistry and Physics, or Biology and Chemisty. Mrs. Koh taught secondary 4 students (Grade 10), aged between 15 and 16, and Mr Low taught secondary 3 students (Grade 9), aged between 14 and 15. The topics chosen by Mrs. Koh and Mr. Low for this study were stoichiometry, and acids, alkalis and salts respectively. On the other hand, Miss Lim and Miss Loh, taught Pre-University 1 students aged

between 16 and 17 at two junior colleges and chose the same topic which was Atoms, Molecules and Stoichiometry for this study. The students involved in Cases 1, 2, 3 and 4 numbered 66, 10, 10 and 8 respectively.

The author of this paper conducted two workshops on the two strategies with the teachers. They were also briefed on the purpose of the study that included the rationale and implementation of the intervention programme. The instructions of the intervention programme were the same as reported by Lee (1993). The teachers were provided with the materials to be used for the programme. In addition, they were also given some guidelines for the evaluation of the programme by using either quantitative or qualitative approach.

For the design of the case studies, Mrs. Koh used the quantitative approach involving an experimental group and a control group whereas the other three teachers used the qualitative approach. Mr. Low, Miss Lim and Miss Loh instructed their students to think aloud their thought processes (protocols) while solving problems. The protocols were audiotape recorded by the teachers. The students of all cases were asked to solve two or three chemistry problems designed by the respective teachers according to the students' abilities for assessing students' problem solving performance before and after they were taught the programme. Table 1 summarizes the teachers in-charge, numbers of students involved in each case, levels, subjects and ages of students, and topics and research methods used in the case studies.

Procedure of Implementing the Intervention Programme and Data Collection

1.A pre-test was administered to the students of all four cases by their research teachers before the students were taught the two strategies. In addition, except for the students of Case 1, each student's protocol was tape recorded while solving the problems on papers.

2.Except Mrs. Koh, the teachers employed the same procedure as described by Lee (1993) to teach the two strategies to their students in two workshop sessions (1Ω hours per session). Due to time constraints, Mrs. Koh conducted the teaching of both strategies in one double-period workshop lesson (1Ω hours) to the students of the experimental group. She played the role of problem solver and demonstrated the solving of a chemistry problem while verbalising the thinking process to the whole class. At the same time, She also identified which of the 6 stages in the McMaster 6-Step strategy she was at by placing a marker on the overhead transparency containing the McMaster strategy board.

3.During the practice sessions, except for Case 1, the students practised in pairs, one being the problem solver and the other the

listener, solving problems using the think-aloud strategy in the first workshop and then both strategies in the second workshop. For the students of Case 1, they only practised in pairs to solve problems using both strategies at the same time in one workshop. The students swapped roles after a problem was solved. First, the content-free problems were used. Then the chemistry problems followed.

4.As the follow-up, the students were given some more chemistry problems belonging to the same topic as home work to practise the strategies by themselves.

5.A post-test, designed parallel to the pre-test of each case, was administered to the students 2-3 weeks after the implementation of the programme by the individual teachers. Again, except for the students of Case 1, the students' protocols were also audiotaped while solving the problems.

Table 1
The Teachers, Number of Students, Students' Levels, Subjects and Ages, Topics, and Research Methods

| Case | Teacher | No. of Students | Level | Subject | Age | Topic | Research Method |
|---|---|---|---|---|---|---|---|
| 1 | Mrs. Koh | 66 | Sec 4 | Combined Science | 15-16 | Stoichiometry | Quantitative Approach |
| 2 | Mr. Low | 10 | Sec 3 | Combined Science | 14-15 | Acids, Alkalis and Salts | Qualitative Approach |
| 3 | Miss Lim | | | | | | |

10
Pre-U 1
Chemistry
16-17
Atoms, Molecules and Stoichiometry
Qualitative Approach

4
Miss Loh

8
Pre-U 1
Chemistry
16-17
Atoms, Molecules and Stoichiometry
Qualitative Approach

Results and Interpretations

In this section, the results and the interpretations of the four cases are presented separately. The data of this cross-case study included all the students' written solutions and the tape recorded protocols (Cases 2, 3 and 4 only). The analysis of these data focuses on the comparison of the students' problem solving performance and also on the students' problem solving behaviour before and after the intervention exercise. Marking schemes for performance and coding systems for strategies employed in the protocols were devised by the individual teachers for these purposes.

Case 1 Mrs. Koh (Quantitative Approach)

A total of 66 secondary 4 students from two classes of a Government aided school took part in this case study. One class, Sec 4E2, of 37 students was an experimental group who were taught the intervention programme whereas another class, Sec 4E3 of 29 students was a control group who were taught the traditional method. Four sets of test scores on solving the three problems in Stoichiometry were obtained comprising pre- and post-test scores from the two classes. The analysis of data focused on three areas of computations: (1) the mean and standard deviation of each set of test scores, (2) the paired-sample t-test for the difference between pre- and post-test scores for 4E2 and 4E3 classes and (3) the two-sample t-test for the pre- and post-test scores between 4E2 and 4E3 classes respectively. The paired-sample t-test was used to find out whether there was any improvement in the marks scored in the post-test over those scored in the pre-test by the students within their classes. The two-sample t-test was used to find out whether there was any difference in the pre-test scores between 4E2 and 4E3 and also the post-test scores between 4E2 and 4E3 classes. The

t-test was used to test the null hypothesis SYMBOL 109 \f "Symbol" = 0 against the alternative hypothesis SYMBOL 109 \f "Symbol" SYMBOL 185 \f "Symbol" 0 at the 0.05 level of significance for the different set of tests between the two groups of students. The means, standard deviations, and the t-test results are shown in Table 2.

Table 2
Case 1: The Means, Standard Deviations, Paired-Sample T-Test and Two-Sample T-Test Results of the Experimental Group (4E2) and Control Group (4E3) Students

| Group | Pre-Test | Post-Test | Post-Test Scores - Pre-Test Scores | Paired-Sample T-Test |
|---|---|---|---|---|
| 4E2 (Experimental Group) | | | | |
| N = 37 | | | | |
| Mean (S.D.) | 3.30 (3.87) | 7.05 (5.97) | 4.11 (5.70) | 5.70 |
| | | | | P = 0.000 |
| | | | | Significant |
| 4E3 (Control Group) | | | | |
| N = 29 | | | | |
| Mean (S.D.) | 1.59 (2.41) | 2.11 (2.96) | 0.82 (1.81) | 2.41 |
| | | | | P = 0.012 |
| | | | | Significant |
| Two-Sample T-Test | | | | 2.20 |

P = 0.032
Significant
4.13
P = 0.0002
Significant
4.12
P = 0.00
Significant

-

The paired-sample t-test results indicate that both groups showed improvement in their post-test compared with their pre-test. From the t-test between the different scores (Post-test score - Pre-test score) of the two groups, the t-value (4.12), implies that the class 4E2 made greater progress than the class 4E3 which suggests positive effect of the intervention programme on students' problem solving performance. However, the entry levels of the two groups of students were not the same as can be seen from the pre-test means of 4E2 and 4E3 groups. Even though the difference between the two groups' post-test means was larger than the difference between the two groups' pre-test means, we still could not conclude that the greater improvement in problem solving of 4E2 over 4E3 was totally due to the teaching of the intervention programme. It could also probably be attributed to other factors such as the inherent abilities of the students from 4E2.

On the basis of her observation, Mrs. Koh commented that 4E2 students were more motivated to solve the problems in the post-test than in the pre-test whereby during the pre-test they just gave up after reading the first few lines of the problems and stared into space. On the other hand, most of the 4E3 students gave up the post-test after reading the problems. The 4E3 students appeared neither confident nor motivated to solve the problems. Since the students of 4E2 were exposed to the programme, Mrs. Koh believed that some positive effect of the programme, specially that of confidence in solving problems, must have rubbed onto them although it is statistically inconclusive.

She recommended that the intervention programme could be taught in schools for science subjects for the development of problem solving skills.

Case 2 Mr. Low (Qualitative Approach)
Ten Secondary 3 art students who took Combined Science and were taught by Mr. Low on the Chemistry component were involved in this case-study. The topic on Acids, Alkalis and Salts was chosen for this study because firstly the students had learnt some basics of this topic in Secondary 2 and secondly the problem solving in this topic was less algorithm oriented and laid more emphasis on conceptual understanding

and application. Mr. Low spent about half an hour to revise with the students the basic theories and concepts of the topic which they had learnt before introducing the intervention programme. Pre- and post-tests which comprised two problems and their parallels were also conducted before and after the intervention programme. Recording of each student's protocol was carried out during both tests. For the analysis of data, the problem solving performances of the students in the pre- and post-tests were scored based on the marking scheme and classified as successful (S), partially successful (PS), unsuccessful (US). Table 3 summarizes the results of students' problem solving performance in the pre- and post-tests. The students' protocols were also analyzed, based on the coding system devised, to compare their problem solving behaviour before and after the introduction of the intervention programme. Table 4 summarizes the students' problem solving behaviour during the pre- and post-tests.

Table 3
Case 2: The Students' Problem Solving Performance in the Pre- and Post-Tests

| Problem | Pre-Test | Post-Test |
|---|---|---|
| 1 | 10 US | 10 US |
| 2 | 10 US | 2 PS 8US |

Table 4
Case 2: The Students' Problem Solving Behaviour in the Pre- and Post-Tests

| Pre-Test | Post-Test |
|---|---|
| 1.Incomplete and imprecise knowledge | 1.Poor and imprecise knowledge |
| 2.Gave up easily when given unfamiliar problem | 2.Six students became more motivated in solving problems |
| 3.Spent very little time in comprehending the problem | 3.Four students showed improvement in verbalizing of their thought processes during problem solving |

4.Used trivial and irrelevant information, tended to guess the answers, were unable to form links between different parts of the problems
4.Three students were more thorough in defining and making relevant translation of the problems

5.Made no attempt to check their answers
5.Four students checked their answers

From Table 3, it can be seen that there was not substantial improvement in the students' problem solving performance after having gone through the intervention programme. According to Mr. Low, the failure of students to solve the problems had been greatly due to the students' inadequate knowledge pertaining to the problems. Another possible reason was the students' inexperience and lack of confidence in solving chemistry problems as chemistry was not one of the main subjects in art classes. Finally, the schedule of the intervention programme using only two workshops was too short for the students to develop effective problem solving skills. However, as can be seen from Table 4, a few students did become more aware of the newly taught problem solving skills and showed some change in their problem solving behaviour. Mr. Low suggested that more sessions should be arranged as an extension of the programme so as to give more time for students especially the weakest ones to practise the two strategies. He also suggested that teachers can also role-play to demonstrate the use of the two strategies in solving some science problems in class.

Case 3 Miss Lim (Qualitative Approach)

Ten Pre-University 1 Chemistry students from a junior college were involved in this case-study. The topic chosen was Atoms, Molecules and Stoichiometry. A pre-test, followed by the intervention programme, and then a post-test were carried out. The pre- and post-tests comprised 3 problems and their parallels respectively. Problem-1 was a familiar problem, Problem-2 a partially familiar and Problem-3 an unfamiliar problem to the students. Each student's protocol was audiotaped while s/he was solving the problems. The data was analysed in the same manner as in Case 2. The analysis focused on two aspects: (1) the students' problem solving performance in pre- and post-tests, and (2) the comparison between the students' problem solving behaviour before and after the intervention programme. Table 5 summarizes the problem solving performance of the students in pre- and post-tests.

Table 5
Case 3: The Students' Problem Solving Performance in the Pre- and Post-Tests

| Problem | Pre-Test | Post-Test |
|---|---|---|
| 1 (familiar) | 7S 3PS 0US | 7S 1PS 2US |
| 2 (partially familiar) | 4S 3PS 3US | 8S 1PS 1US |
| 3 (unfamilar) | 1S 7PS 2US | 5S 3PS 2US |

Table 5 shows that there was very little difference in the students' problem solving performance between the pre- and post-tests for Problem-1 (familiar). However, more students had got the correct solutions in the post-test for Problem-2 (partially familiar) and Problem-3 (unfamiliar) as compared to the pre-test. More students obtaining correct answers could mean that the use of the two strategies taught to solve problems had an effect on their achievement.

The protocols were also analyzed to explore the change in the students' problem solving behaviour before and after the intervention programme. Table 6 summarizes the comparisons of the students' problem solving behaviour during the pre- and post-tests. Miss Lim commented that even though there was significant improvement in the students' problem solving performance between pre- and post-tests (Table 5), due to the small sample size, the effectiveness of the teaching of the two strategies could not be statistically conclusive unless a larger sample was used. However, the analysis of the students' protocols showed that most of the students had incorporated, to some extent, the think-aloud and McMaster problem solving strategies in their post-test problem solving, although they had not incorporated all the aspects of the strategies (Table 6). Miss Lim believed that the intervention programme did improve the students' problem solving performance and skills and commented that the results would have been even better if more time had been alloted for practice. She recommended that teachers should try to incorporate the teaching of these two problem solving strategies as part of the curriculum.

Table 6

Case 3: The Students' Problem Solving Behaviour in the Pre- and Post-Tests

Pre-Test
Post-Test

1.The students did not read the whole problem aloud, they either did not read the problem statement at all or read only parts of it.
1.All the students read out aloud the problem statement.

2.Most students did not define and analyze the problem statement, they began by plunging into the problems and tried to work out the solution straight away.
2.The students tended to spend more time to explore and define the problem statement before planning how to solve it. Fewer students felt confused and indecisive as to what to do.

3.Four students checked their answers.
3.Seven students checked their answers.

Case 4 Miss Loh (Qualitative Approach)

Eight Pre-University 1 Chemistry students from another junior college were involved in this case-study. The topic, the problems used for the pre- and post-tests, and the administering procedure of the intervention programme were the same as in Case 3. (Note: Since the ability and level of the students in Case 3 and Case 4 were very similar, Miss Lim and Miss Loh decided to jointly design the two

case-studies.) Table 7 summarizes the problem solving performance of the students in pre- and post-tests. The students' pre- and post-test protocols of each problem at each stage of the McMaster 6-Step strategy were also analyzed and identified. Table 8 summarizes the stages used by the students for solving the 3 problems during the pre- and post-tests.

Table 7
Case 4: The Students' Problem Solving Performance in the Pre- and Post-Tests

Problem
Pre-Test
Post-Test

1
(Familiar)
4S 1PS 3US
6S 2PS 0US

2
(Partially familiar)
0S  4PS  4US
2S  0PS  6US

3
(Unfamilar)
0S  2PS  6US
3S  0PS  5US

Table 8 shows that the students in general made considerable progress in the use of the general problem solving strategy in terms of the six stages for solving the 3 problems after receiving some training of problem solving skills through the intervention programme. The improvement of problem solving skills among these students was also reflected in their problem solving performance as more students had got the right solutions (Table 7), but not to a great extent. The reason for this, according to Miss Loh, was that there were other factors which were also important in determining their performance as, for example, the prior knowledge pertaining to solving the problems.

Table 8
Case 4: The Comparisons of Stages Used for Solving the 3 Problems in the Pre- and Post-Tests

Problem
Test

Stages

Read
Define
Explore
Plan

Do It
Look Back

1
Pre

8
3
5
3
8
5

Post
8
6
7
6
8
4

2
Pre
8
5
3
2
8
5

Post
8
7
7
6
8
7

3
Pre
8
5
3
3
8
5

Post
8
7
5
4
8

On the basis of the students' protocols, Miss Loh commented that the students used the think-aloud and general problem solving strategies taught to begin the solving and relied on these skills to guide them through the problems in some cases. They had not yet become experts, and as such had difficulty in getting the problem completely right. She was not surprised because problem solving is a complex cognitive skill which cannot be mastered in a short period of three weeks class. However, it was evident that the students were making progress in developing the problem solving skills. Miss Loh considers the think-aloud strategy a good method to make students more aware of their own thinking process and as a result to enhance their conceptual level. Her students found that the two problem solving strategies were useful and had helped to raise their confidence in problem solving. She suggested that the intervention programme should be recommended for teaching junior college science students. It prevents students from being passive learners and makes them constantly aware of their own thinking process.

## Conclusion and Implications

Irrespective of which particular approach - quantitative or qualitative - was used, the four case-studies undertaken in a period of about three to four weeks with the different level of students, highlighted one common result: the students showed considerable progress, especially in their problem solving skills. They became more motivated and confident in solving chemistry problems (Case 1 and Case 2). Many students incorporated the think-aloud strategy in their problem solving (Case 3 and Case 4). The students showed signs of spending more time and were more systematic in translating the problem statements (Case 2 and Case 3). They were more particular about checking the answers or solutions (Case 2 and Case 3). These results support the findings in the previous studies (Bunce, Gabel and Samuel, 1991; Pestel, 1993) which suggested that the teaching of problem solving strategies were useful for students in tackling unfamiliar or complex problems.

For the problem solving performance, the students' improvement was also observable, though it was not statistically evident due to small sample sizes. On the basis of the overall results of the cross-case study, it was observed that the students' problem solving performance did not always improve alongside with their problem solving skills. Two reasons commonly maintained by the teachers were that successful problem solving was also determined by the availability of adequate knowledge pertaining to the problems in addition to the problem solving skills and the time for the students to practise the two strategies was too short. Moreover, the students of Pre-University (Case 3 and Case 4) or of higher ability group (Case 1) appeared to take the

intervention programme better and showed a greater progress than the weaker students in science (Case 2).

The teachers have made two suggestions for improving the intervention programme and the teaching of problem solving skills in class: (1) teachers can role-play to demonstrate how the two strategies can be used for developing problem solving skills, (2) more time can be allocated for the intervention programme as a follow-up practice with suitable chemistry problems especially for the weaker students.

This preliminary study shows that the intervention programme has potential for developing students' problem solving skills. Since this study employed only a few subjects in each case, a wider application is not yet fully justified. The implication of this study for further research is that a larger scale of action research can be pursued in schools to test its findings and to explore the feasibility of implementing the intervention programme in school curriculum.

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