EXPLICIT TEACHING OF PROBLEM-SOLVING STRATEGIES IN SCIENCE

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INTRODUCTION

The development of the field of research in problem solving is particularly vast and rather disorganised and this has been shown to be true even in the limited area of science education (Garrett, 1986). A model of problem-solving strategy is an organised approach that breaks mental task of problem solving down into stages. It is applicable to a range of problems on different subject areas. Such a model is derived either from personal perceptions of an accumulated experience of problem solving or from results obtained in research on problem solving. This paper discusses two types of problem-solving strategies, namely stage-type general problem-solving strategy and investigative-type problem-solving strategy. It is important to teach explicitly problem-solving strategies as part of science curricula at all levels. A problem-solving strategy helps us to tackle parts of the problem-solving process systematically, one part at a time, especially for solving an unfamiliar or a difficult problem.

STAGE-TYPE GENERAL PROBLEM-SOLVING STRATEGIES

A number of stage-type general problem-solving strategies has been reported in the literature of different fields such as science, psychology, business, administration, philosophy, music, art, engineer, and nursing. Although the words used and the lines drawn between them vary, the stages or steps are similar. Among the models for solving problems there are several common stages: (1) accepting and understanding the problem, (2) planning a solution, (3) implementing the plan, and (4) testing/checking the results that lead to a solution. When a problem solver is presented with a problem, s/he prepares her/himself to solve the problem. S/he attempts to understand the problem statement by defining the problem, distinguishing the essential features of the situation, and identifying the goal/subgoals for the problem. Once s/he works out the meanings of the problem statement, s/he proceeds to the next stage of planning a solution by formulating the procedure that may be applicable to the solution. In the stage of implementing the plan, s/he generates possible solutions using the available background information and rules of inference. When the solution is obtained, the solver assesses it. The following example using a typical volumetric problem illustrates the problem-solving processes involved in the four stages.

Example

Problem: Starting from a concentrated HCl solution, 5.0 litres of a dilute 0.1 M solution has to be prepared. The concentrated acid has a density of 1.13 g/ml; it contains 25.5% (by weight) HCl. How many millilitres of the concentrated HCl solution are needed?

In Stage 1: Accepting and understanding the problem

The problem solver reads the problem carefully. S/he analyses the problem statement, using paper and pencil to develop an image of the problem situation. S/he plots or sketches a graph to get a better image of the problem situation. S/he writes down the known and unknown in words and symbols. S/he sets the goal(s) or sub-goal(s) for the problem. See figure 1 for illustration.
In Stage 2: Planning a solution

Backward calculation may be considered using the known information gathered in Stage 1. This problem can be solved in three steps:

1. Using known $C_2$ and $V_2$ to calculate the number of moles of HCl contained in Solution 2.
2. Using known density and mass fraction of Solution 1 to calculate the number of moles of HCl in one litre of Solution 1.
3. From the results of Step 1 and Step 2, calculate the volume of Solution 1 that is needed for preparing Solution 2.

Stage 3: Implementing the plan

1. The number of moles of HCl in 5 litres of Solution 2 = 0.1 x 5 = 0.5 moles
2a The number of moles of HCl in 1 litre of Solution 1 = Mass of HCl in 1 litre of Solution 1 / Molar mass of HCl
2b Mass of HCl in 1 litre of Solution 1 = 1.13 g/ml x 1000 ml x 0.255 = 288.2 g
2c The number of moles of HCl in 1 litre of Solution 1 = 288.2 / 36.5 = 7.9 moles
3 The volume of Solution 1 needed for preparing Solution 2 = 0.5 / 7.9 = 0.0633 litres = 63.3 ml

Stage 4: Testing/Checking the results

Using the formula $C_1V_1 = C_2V_2$

$C_1 = 7.9$ mol/litre $V_1 = 0.0633$ litres $C_2 = 0.1$ mol/litre $V_2 = ?$ litres

$V_2 = C_1V_1/C_2 = 7.9 \times 0.063 / 0.1 = 5$ litres

Since the volume of Solution 2 is 5 litres, the same as the known given in the problem statement, the answer is correct.
Table 1 lists stages of problem-solving strategies proposed by contemporary researchers. We use three phases to summarise the similarities. Phase 1 involves the above Stage 1: the accepting and understanding the problem. Phase 2 includes Stage 2: planning a solution and Stage 3: implementing the plan to generate a solution. To some researchers, these two stages are inseparable in the process of executing the solution. This explains the necessity of combining these two stages together in one phase. Phase 3 is the Stage 4: the process of testing and checking the solution.

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<td>Johnson (1961)</td>
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<td>Lee &amp; Fensham (1996)</td>
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INVESTIGATIVE-TYPE PROBLEM-SOLVING STRATEGIES

This type of problem-solving strategies involves the steps of problem solving through investigation. The emphasis here is on the development of higher-order thinking skills. These skills include formulating a question/problem; formulating hypothesis; planning an investigation; setting controlled, changeable and measurable variables; analysing, synthesising and evaluating facts and concepts. These strategies comprise steps similar to those in the stage-type general problem-solving strategies. However, the investigative-type problem-solving strategies emphasise problem solving in general, the investigation processes and scientific method in science. Three strategies of this type are briefly described as follows: Bransford and Stein's (1984) model consists of five steps: Identify, Define, Explore, Act and Look (IDEAL). Pizzini and his co-workers’ model consists of four steps: Search, Solve, Create and Share (SSCS) (Pizzini, Abell & Shepardon. 1988; Pizzini, Shepardson & Abell, 1989). Harlen (1985) proposes five questioning steps for investigative problem solving: (1) What is the problem/question? (2) What should be changed in investigation? (3) What should be kept the same? (4) What kind of effect should be observed? (5) How will the result be used to answer the question?

A problem solver is presented with a novel problem that is open-ended with no one definite answer (e.g. In a primary science classroom, a problem is posed: Does a marker ink contain only one colour pigment or a mixture of colour pigments?). The solver has to identify, search, and define a problem situation by formulating the problem/question and a hypothesis for it (Possible hypothesis for the above problem: a marker ink contains a mixture of colour pigments). S/he then explores and plans an investigation. S/he has to determine the variables involved and the procedure of the investigation (Paper chromatography, using inexpensive and readily available materials, can be used for an investigation. Different marker inks are the changeable variables. Same type of paper is used as a controlled variable...etc.). Once the plan is determined, s/he has to carry out the investigation to collect data. In the analysis of data, s/he interprets and checks the results, and then decides whether to accept or reject the hypothesis. S/he shares her findings with others. As a result, s/he learns science concepts through concrete experience of solving problems in science.

APPLICATION OF PROBLEM-SOLVING STRATEGIES IN SCIENCE INSTRUCTION

In recent years, there has been an increasing emphasis on the use of the problem-solving approach in science instruction. Some research evidence has shown that explicit teaching of problem solving processes in science classes can improve students' problem-solving skills, students' cognitive development and science achievement (Huffman, 1997; Heyworth, 1998). Teachers can help students by providing explicit strategies that are procedurally structured to encourage students to become involved in their own learning and undertake the steps necessary to solve problems in science (Pizzini, Shepardson & Abell, 1989; Niaz, 1995).

A few nation-wide American studies (Bredderman, 1982; Shymansky, Kyle & Alport, 1983) reviewed the effectiveness of Elementary Science Study (ESS), Science. A Process Approach (SAPA) and Science Curriculum Improvement Study (SCIS) activity-based, process-oriented curricula on students' learning outcomes in elementary science. Each study reviewed included a control group that received comparable content instruction from a textbook. The results of these studies show unanimously that the process-based curricula had a more positive impact on student performance across all measures including process skills, creativity, attitudes, logic and science content than the textbook-oriented curricula. Problem solving is supported through the acquisition of process skills by activity-based, and process-oriented elementary science curricula.

Even though much is known about what strategies nurture productive problem-solving behaviour, there is evidence that many of the strategies are not being implemented into the majority of both secondary and elementary science classrooms. In many classrooms, there still seems to be a great emphasis on coverage of factual material (Newmann, 1988). In the '80s, it was found that most science students did not conduct even one experiment in which the solution was unknown throughout
the academic year (Brandwein, 1981). It seems there has been very little progress during the subsequent fifteen years later. Many science teachers hardly conduct activities pertaining to problem solving (Lawrenz, 1990; Chin, Goh, Chia, Lee, & Soh, 1994; Tan, 1997). What are the difficulties associated with teaching problem solving?

In Tan's survey study (1997), it was found that about two-thirds of the primary science teachers in Singapore seldom conducted science lessons using the problem-solving approach. Most of the science teachers were more concerned about external factors that affected their implementation of the problem-solving approach, factors such as covering the science syllabus in time for examinations, physical constraints of the learning environment and student's ability and motivation. On the other hand, teacher-related factors ranked low: these included teachers' preference of teaching and learning outcomes, their ability to maintain control over students' learning, feelings of inadequacy in terms of science knowledge, and insufficient understanding of the pedagogical method of teaching problem solving.

TEACHING IMPLICATIONS

In general, there are at least five common concerns about teaching problem solving (Law, 1999). The first concern is about whether problem solving can be taught. This concern is especially true when the learners are expected to search for novel, original and new answers. When learners encounter with ill-defined problems or are exposed to investigative problem-solving models, they are challenged with situational and dynamic problem-solving conditions. The basic problem-solving steps can be taught using incremental and systematic instructions. For well-defined problems using the step-type problem-solving models, teachers and learners can predict the goal states when they approach the initial state of the problem. Teachers have to be aware of the "openness" and "complexity" of guiding learners to solve ill-defined problems. They should be alert of the difficulties in coaching problem solving that can lead to multiple solutions.

The second concern is related to learning prerequisites for solving a problem. To solve a problem within a domain such as in science, a problem solver has to be equipped with the domain-specific knowledge and skills in addition to her/his cognitive competence, and affective readiness (motivation) to participate. Finding novel solution to a problem demands an individual's multiple skills and competence. Teachers should be aware of the multiplicity of skills and competence in solving a problem. It is unwise to view problem solving as a hierarchical process governed by a series of steps. Most real life problems, complex problems, and ill-defined problems require recursive problem-solving strategies. A person has to be able to identify flaws that may lead to unsuccessful solutions during the problem-solving processes. When dealing with domain-specific problems, an individual has to acquire the domain-specific contents which allow her/him to identify and represent the problems.

The third concern is about the competence of a problem solver to represent her/his problem. Teachers should be aware of the importance to encourage learners to find ways and strategies to represent the given problems. It is believed that the ability to represent problem is the most important competence for solving any problem. The problem solvers have to search for the relationships between the given information and the existing problem; and/or between the structures of the existing and those of the past problems. The search phase can be complex. Until the problem solver arrives at a network of knowledge and expertise that matches the present problem, s/he can not propose effective problem-solving strategies or plans.

The fourth concern addresses the non-cognitive characteristics of problem solvers. The dispositions of problem solver are crucial for outlining successful problem solving strategies. Open-mindedness, dedication or whole-heartedness, and responsibility are three of many important dispositions that problem solvers should possess. When engaging in collaborative problem solving, individual problem solvers have to be committed to the task, and open to viewpoints of others, and responsible for her/his
allocated tasks. For getting novel solutions, the individual's commitment and dedication are especially indispensable.

The fifth concern is related to the qualities that teachers need to possess in order to be able to teach or coach problem solving effectively. In teaching science problem solving, teachers should be competent in the science theories and concepts, problem-solving models, and assessment techniques that can capture novel and useful solutions. Teachers should attempt to model problem-solving dispositions and strategies. Modelling is one of the most effective instructional techniques. Teachers should also try to infuse and integrate various thinking skills and dispositions into lesson delivery. By observing how teachers solve problems with confidence and flexibility, learners gain interest in using various types of problem-solving strategies.

REFERENCES


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