PSYCHOLOGY FOR TEACHERS: GENERAL PROBLEM SOLVING AND PROBLEM SOLVING IN SCIENCE EDUCATION

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Abstract: Problem solving is an important topic in various school subjects such as mathematics and sciences. The models problem solving and steps proposed to solve a problem have been one of research areas in psychology. This paper intends to provide an overview of psychology of problem solving and various themes of problem solving proposed by psychologists. First the classical examples of problems are presented. Then, features of social and non-social problem solving are discussed. In addition, the individual and group problem solving styles are introduced. Furthermore, generic and domain-specific problem solving are elaborated. For the discussion of psychology of problem solving in education, we highlight models of problem solving in science education, the application of problem solving in science education, and difficulties of teaching problem solving in schools. Lastly, implications of models and application of problem solving for educators are presented.

General Problem Solving

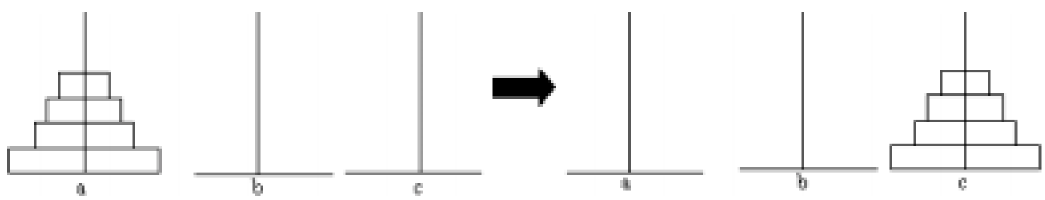
Problem solving is one of the significant themes in psychology. From the psychological database, Psyclit (1993-September 1999), using the key word "problem solving", we can find a high frequency of the appearance of this term which is comparable to that of an established psychological construct "intelligence". As early as at the beginning of this century, problem solving was studied in the laboratory intensively by the psychologists. It was investigated together with cognitive concepts such as reasoning, memory, intelligence, etc., and was regarded as higher mental processes. As problem solving is a form of higher-order thinking, and the philosophy of thinking can be tracked back to the beginning of human civilization, it is thus difficult to set a historical date for the start of the study of problem solving. Nonetheless, we can claim that problem solving attracted the psychologists' attention from the beginning of the twentieth century, and the empirical problem solving research began to flourish in the early sixties with the birth of the information processing approach (Law, 1999).

What is a problem? When an individual encounters a state of difficulty in a situation or with a task that s/he never before experiences and does not know ways to solve it, s/he faces a problem. A problem exists because the individual has a goal to attain but does not know how to proceed from the *givens* (or the initial point) to the *goal* (state). S/he encounters *obstacles or barriers*. An example of a problem is arranging six alphabets n, m, o, a, r, l into a meaningful (English) word. A person who is given this problem could recognize the individual alphabets, but is in search of a "form" or a "pattern" that makes sense. One of the barriers of this problem is the "unfamiliar" arrangement of the alphabets. The person has to move the alphabets to various positions so that after a series of arrangements s/he could come out with a word that can be found in the dictionaries. In this example, the person knows the goal state (her/his vocabularies), but is yet to find out ways to transfer the current state (arrange the alphabets).

Without the presence of *obstacles*, a person does not encounter a problem, and hence problem solving does not take place. Instead s/he is given a task to complete. We use an example to illustrate our statement. An individual (A) is requested to find the answer for a sum 8 x 9. Instantly, s/he presents the perfect answer 72. For her(him) the given sum is not a problem, but is a task to be completed. Another individual (B) who has not learned the multiplication table is presented with the same sum. S/he is unable to arrive at the correct answer instantly. S/he encounters a problematic situation. Referring to the individual's (A) and the individual's (B) experiences, it is clear that for some people a sum 8 x 9 is a task, whereas for some other persons it is a problem. Individual B has to understand the 8 x 9 meaning of "x" before s/he could arrive at the answer.

There are various types of problems. In this paper, we highlight *well-defined* and *ill-defined* problems. We claim that recognizing these two types of problem is essential especially in the everyday context. Often in the classroom, learners are given well-defined problems. However in real life, they face ill-defined problems. When the *givens* and the *goal* are clearly defined, a problem belongs to the well-defined category. Examples of *well-defined* problem are arranging six alphabets into a meaningful word (or anagram) and solving a multiplication sum. Among well-defined problems, there are *product*-oriented and *process*-oriented challenges. A problem can be product-oriented and process-oriental. In product-oriented p/s, the problem solver aims at getting the final answer without paying intensive attention to the steps. We cite the Hanoi-tower problem as one of the examples of the *process*-oriented problem. The challenge that a person faces with the Hanoi-tower problem is to reconstruct the same tower by moving the plates from the initial state (a) to the goal state (c) by going through a transitional state (b) (see Figure 1). The problem solver has to set his mind to the steps or the processes, to search for the "right" strategies to move and reconstruct the tower.

Figure 1: The Hanoi-Tower Problem



The initial state The goal state

An *ill-defined* problem is "open" because *the givens* and *the goal* are unclear. In other words, an *ill-defined* problem has an unclear initial state and an indefinite goal state. Most of our everyday, social, interpersonal, and economic problems are *ill-defined*. Let us examine several sentences written by Georg Kueffner, the editor of the Frankfurter Allgemeinen Zeitung (June 1996 the *Paper News*, a magazine that discusses current concerns). The title of his article was "Der Wald -- der Deutschen zweitliebstens Kind" (Forest -- the Germans' second most fond child). In page five, he wrote "Whoever drives in the forest on Sundays after a luxurious lunch will have his/her unique thoughts on the second most fond child of Germany, after the automobile. An example of such thoughts could be: What could our children and grandchildren benefit from the forest, one day?" Kueffner voiced out his concern about the endangered forest and his love for the nature. The issue of conserving environment for a better quality of life and for future generations is a complex problem. It is also an example of ill-defined problem.

What is problem solving? We refer to Newell and Simon's (1972) notion of *problem space* for the definition of problem solving. *Problem space* consists of physical or cognitive states that are achievable by a problem solver. Hence, problem solving refers to a search for a problem space. According to Law's (1999) review on Newell and Simon's work, there are several general problem solving methods or *heuristics* which can be used to propose a sequence of operators (or actions) that can lead to the traversal of the problem space. In Table 1, five general problem solving methods and general problem solving processes are listed. We elaborate in details problem solving processes in the next section when we discuss problem solving in science education.

Table 1: Heuristics and General Problem Solving Processes

Heuristics	General problem solving processes
• The difference-reduction method - Select operators that reduce the difference between the initial state and the goal state. • The means-end analysis method – Same as the difference-reduction method except it involves setting of the sub-goals. • The working-backward method – First the goal state is identified, and from there the problem solver moves towards the initial state. • The generate-and-test method – Alternative courses of action are generated, and search for the workable method. • Analogy – Use the structure of one problem to guide the solution to another problem.	• Problem identification or problem finding • Constructing a (mental) representation • Planning • Strategy selection • Monitoring solution

Main source: Law (1999)

Social problem solving versus non-social problem solving: Social problems are complex and ill-defined. Solving problem solving involves people with different personalities and various sets of problematic situations. The problematic situation is dynamic, and varies according to time, space, and persons. A problem solver has to employ a dynamic and situational problem solving framework as s/he moves from the initial state to the goal state. S/he may find her(him)self uses various strategies, and re-orientes the goal (sub-goal) states, as s/he moves from the intial state to the goal state. In the literature, social problem solving concerns complicated human related and interpersonal problems such as coping with stress, depression, traumatic experiences, disorders, etc. In constrast, non-social problem solving involved a relatively defined set of variables. Non-social problems are such as problems in the manufacturing sector, computer technology, engineering, etc. The variables can be multiple, but they can be represented relatively clearly using mathematical or statistical models. A problem solver has to acquire ample skills and knowledge in proposing plausible strategies that can lead her(him) successfully from the initial state to the goal state.

Group versus individual problem solving: Group or collaborate problem solving often refers to the study of how individuals work effectively in a team, as opposed to working alone. The problems in collaborative problem solving are usually related to everyday normal situations in the industry, organisations, classrooms, etc. Team work and co-operation are two frequently related terms. The main aim of collaborative problem solving is to gather expertise and skills from various teams who specialise in different domains. Modern education is specialized in nature, and hence an individual is usually educated in one or two specific areas. Group problem solving can be important to brainstorm ideas that may bring a wide perspective beyond an individual’s capacity.

General versus domain-specific problem solving: Educators concern of how to apply general problem solving strategies or processes proposed in the psychological literature to various subjects or disciplines. While general problem solving may seem to focus on mental processes and cognitive strategies, domain-specific problem solving may seem to highlight the application of problem solving strategies that may lead to the increase of quality of work. While some researchers may favor the transfer of general problem solving skills or strategies to specific domains, some may think that it is essential to develop problem solving skills or strategies within a discipline or domain. In the next section, we address domain specific problem solving in science education.

Problem Solving in Science Education

The field of research in problem solving is particularly vast and largely disorganised and this has been shown to be true even in the limited area of science education (Garrett, 1986). A model of problem solving is a general approach to solution that is applicable to a range of problems whatever their subject content is. It may not be necessarily appropriate for every particular problem or problem solvers. Such models are 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 models, i.e., stage-type problem-solving models and investigative problem-solving models.

Stage-type problem-solving models: A number of stage-type problem-solving models have been reported in literature. They have similar stages or steps, although the words used for them vary, as also does the line drawn between them. 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(him)self 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 endeavours to generate possible solutions using the available background information and rules of inference. When the solution is obtained, the solver assesses it.

Table 2 lists stages of problem solving models proposed by contemporary researchers. We use three phases to summarise the similarities. Phase 1 involves the accepting and understanding the problem. Phase 2 includes planning a solution and 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 concerns the process of testing and checking the solution.

Investigative problem-solving models: This type of problem-solving models 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 models comprise steps similar to those in the stage-type problem-solving models. However, whereas the stage-type problem-solving models emphasise problem solving in general, the investigative problem-solving models emphasise hands-on experience, investigation processes and scientific method in science. Three models 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 & Shepardson, 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. The solver has to identify, search, and define a problem situation by formulating the problem/question and a hypothesis for it. S/he then explores and plans an investigation. S/he has to determine the variables involved and the procedure of the investigation. 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.

Table 2: Stage-Type Models of Problem Solving Process

Researchers	Proposed Stages Phase 1	Phase 2	Phase 3
Reif & Heller (1982)	1. Redescribing or translating the problem	2. Searching for the solution	3. Assessing the solution
Casey & Frazer (1984) Frazer (1982)	1. Defining	2. Selecting 3. Combining	4. Checking
Ausubel and Robinson (1971)	1. The problem is presented to the problem solver. 2. Relating the problem to the solver's cognitive structure and understanding the problem by him or her	3. Generating possible solution	4. Checking the solution
Johnson (1961)	1. Preparatory	2. Solution	
Gagné (1977)	1. The solver is presented with a problem to be solved. 2. Defining the problem and distinguishing the essential features of the situation	3. Formulating hypotheses 4. Verifying the hypotheses, till (s)he gets the solution	
Robertson (1983)	1. Clarifying and defining	2. Collecting or selecting the appropriate information 3. Combining or reasoning with the separate bits of information	4. Checking
Woods (1985)	1. Reading I want to and I can. 2. Defining the stated problem. 3. Defining-explore the issue.	4. Planning the action steps. 5. Doing it.	6. Looking back.
Lee & Fensham (1996)	1. Comprehending the whole problem statement 2. Translating the parts of the problem statement so that they have meaning 3. Setting goal(s) or subgoal(s)	4. Selecting information from the translation 5. Retrieving 'rule(s)' or 'fact(s)' from memory 6. Achieving goal(s) and/or subgoal(s) (by explicit or implicit linking of Processes 4 and 5)	7. Checking the path(s) of the solution or the answer(s)

Application of Problem Solving 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). Teacher 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). This is applicable at both the secondary and elementary levels.

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 Eighties, 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 a 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.

Implications for Teachers

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 step. Most real life problem, complex problem, and ill-defined problem 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 representing phase is the most difficult phase for many problem solvers, as they have to search for the connections between the givens and the problem, and the problem with the structures of the past problems that they have encountered. 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 flexibly and with confidence, learners gain interest in using various types of problem solving strategies. To ensure teachers have ample confidence in using problem solving strategies, teacher educators as well as psychologists should examine the difficulties of teaching problem solving in various disciplines in the classrooms. Unless teachers, teacher educators, and psychologists have identified common problems and the necessity to search for effective models for teaching problem solving, the journey to stimulating novel and multiple solutions is still as complex and vague as it has been.

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