ON TEACHING PROBLEM SOLVING
Part 1: What Is Being Done?

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PROBLEM SOLVING—what is it? where does it fit into a training or educational program? and how do we teach it?

The range of response to 1000 questionnaires sent out to try to find answers to these questions ranged from incredulity that anyone should ask such a question, ignoring the questionnaire (the response was 8%), to interest in the topic, but no specific suggestions at this time, to very stimulating interest responses.

This summary discusses the initial problem of definitions, and what experience is being offered (content and method). The challenges or difficulties as seen by the respondees and some idea of how one might use the information here summarized to introduce or improve the teaching of problem solving are discussed in Part II.

Defining what we mean by solving problems is not easy. A problem could be defined as a stimulus situation for which an organism does not have a ready response [1] or more formally as a specific situation or set of related situations to which a person must respond in order to function effectively in his environment. The situation is one where no effective response alternative is immediately available to the individual confronted with the situation [2]. One could identify problem solving as the activity whereby a *best* value is determined from an unknown, subject to a specific set of conditions or more formally—a behavioral process, whether overt or cognitive in nature, which

- **makes available a variety of potentially effective response alternatives for dealing with the problematic situation,**
- **increases the probability of selecting the most effective response from among these various alternatives [2].**

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From a first glance at such an activity as problem solving we can identify [1] a strategy, procedure or set of steps, by which we perform the activity, and [2] elements or skills that are necessary to be able to carry out the steps; for example, being able to analyze or take a problem apart, to generalize, to be creative, to draw logical inferences, to generate hypotheses, to make decisions, to identify criteria etc.

But the two above are not sufficient if the problem solver lacks the prerequisite

- **basic knowledge or manual skills,**
- **attitude or will to solve the problem,**
- **ability to obtain information,**
- **ability to listen or to understand words,**
- **ability to work in groups (if necessary),**
- **experience from which to make judgments,**
- **learning skills.**

- pretest prerequisite background knowledge to ensure this is not the difficulty,
- Study the ideas of Piaget about concrete and formal thought and translate the implications into our courses and worked examples,
- run or attend short study sessions on the development of reasoning,
- use sender-directed problem solving. Rather than just turning the students loose to "solve the homework problems" with the professor available for assistance, the professor starts the session by asking them as a group to define or restate the problem so that every one knows what was expected. He does this by asking: "Bill, what do you think is being asked for?" "Mary, do you agree?", "How many think it is something else?", "I could interpret it as . . . . , what do you think of that interpretation?" He provides the students with an overall outline of the steps in solving problems and by leading the students through the strategy for several steps, for several problems, he hopes they can translate this to solving problems on their own.
- use group or small group tutorial problem solving,
- use different learning environment such as a game or simulation.

Perhaps some more ambitious ideas, that require more time on problem solving, include:

- identify a pattern or strategy for solving problems and then consistently use that strategy for all example problems, for the notes and for the textbook, see, for example, ref. 8
- provide real life problems as case* studies or larger projects that are open-ended where data are missing or inconsistent
- provide more in class demonstrations by the instructor, by students, by someone outside and by the students together
- have students prepare a problem for the professor to solve in the tutorial. The professor thinks aloud while he solves the problem
- prepare self-paced enrichment units for all the prerequisite skills and the problem solving elements
- use a problem oriented approach to learning.

The next group of suggestions demand more commitment not only of time in the program but to the development of special materials that focus only on how problems are solved. The major focus can vary on the one extreme from the *answer* (based on the discipline knowledge with some emphasis throughout being placed on the strategy), to the other extreme where the focus is on the *strategy* and on the elements and the discipline is almost immaterial). Those taking these approaches are shown in the top central region of Figure 1.

*The term case study is used to describe open-ended problems describing real world or simulated real world problems.

A problem could be defined as a stimulus situation for which an organism does not have a ready response or more formally as a specific situation or set of related situations to which a person must respond in order to function effectively in his environment.

Some ideas for this approach include:

- provide a special set of problems to force students to focus on the strategy of solving problems
- use a small group tutorial to solve real case problems
- use design or synthesis type of problem
- use a research type of problem
- use critical instant, deterministic or clinical diagnosis type of problems
- use a textbook centered strategy to solve around open-ended problems such as ref. 9
- use large open ended problems where the student must collect their own data from experiments or from people.

SPECIFIC APPROACHES

CONSIDER BRIEFLY a few details of some selected specific approaches that illustrate the variety.

Gladstone [10], as part of courses on learning and introductory psychology, uses a carefully selected sequence of problems. The students solve a hierarchy of difficult problems given some instructions as to how to go about the task, then they learn a particular problem solving technique and find a problem that can be solved using that technique. They verbally describe how they solve their own problems using the techniques learned in the class.

Marples [11] has developed problem worksheets to help the students to organize their problem solving approach. First Marples suggests that the problem statement can be classified into the artefact, the conditions and the unknown. The known information can be generalized to provide clues as to which theory could be used to create a hypothesis. Via backward reasoning and by relating the hypotheses to subproblems, the structure of the problem solution can be developed. His examples are freshman and sophomore science problems. His paper should be consulted for details.

Van Wie [12] has concentrated on the freshman science-technology problems. Through lec-

In summary, the initial problem in talking about problem solving is to limit the scope.

In this summary, the focus is on those courses or programs that offer training in the application of the strategy and the elements or steps in that strategy, and not to emphasize the courses or programs on the prerequisites (listed above).

WHAT EXPERIENCE IS OFFERED?

TO SUMMARIZE THIS survey, Figure 1 shows the variety of emphasis on the content. On the extreme left of Figure 1 are courses where problem solving is not part of the experience. Naturally no responses were received that are in this category. On the extreme right are experiences where problem solving is the sole emphasis. At the top are those experiences where the emphasis is on the strategy (for example, the steps in solving the problem) while at the bottom are those experiences where the emphasis is on the elements (for example, a course on creativity). Some textbooks are shown on Figure 1 so that this classification may be more apparent.

From this analysis, six characteristic groups were identified. There is no universal answer as to where is the best location on Figure 1; that depends on the local conditions. The classification does identify groups of people from wide ranges of disciplines that are doing about the same things. Each of these six groups are discussed in turn.

Most of us teach courses where the students must learn some basic knowledge: Newton's second law, the law of diminishing returns, or the biochemistry of oxygen transfer. We expect our students to be able to solve problems using that knowledge and eventually to solve real-world problems.

In class, we may solve many example problems ourselves, choose textbooks that have many illustrative problems and assign many problems for homework. Our effectiveness in teaching problem solving skills by this approach depends very much on the consistency and detail presented when examples are worked in class, the faculty-student dialogue during that example, the type of homework problem assignated, the way the question is asked etc. For different courses, there is a varying amount of emphasis that can be placed on the problem solving activity. Those who follow this approach are shown on the left hand side of Figure 1. Some ideas that one might try are: (based on the responses from the survey)

- **have some students work the problems on the board and then have them describe how they did it to the class,**
- **provide a list of a problem solving strategy,**
- **place special emphasis on how to approximate and how to check the answer,**

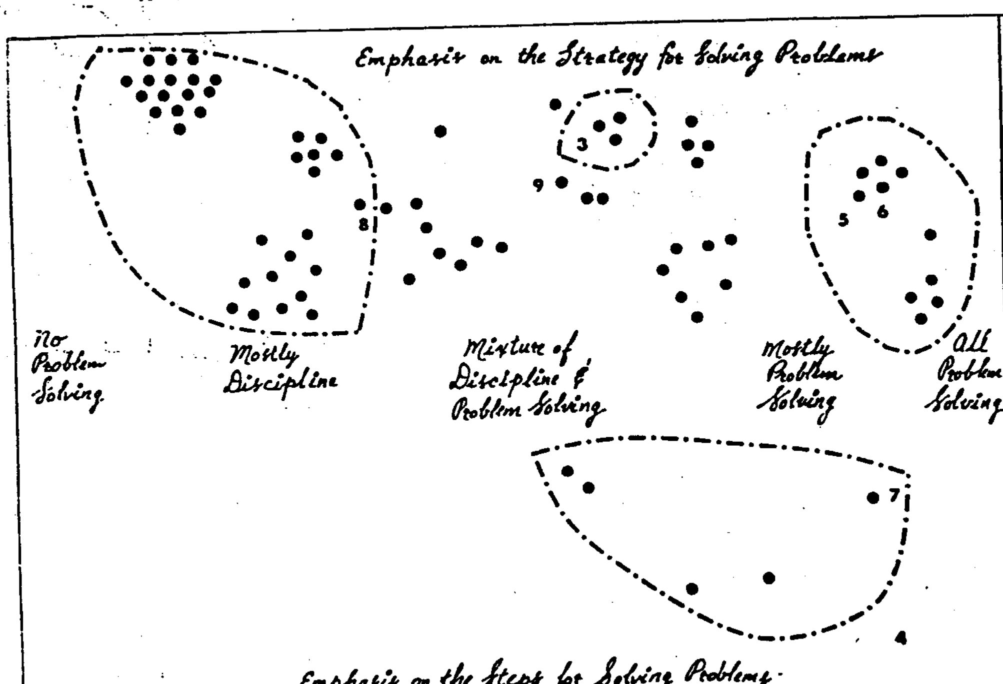

FIGURE 1: A Classification of Approaches

The numerals refer to textbooks listed in the references. Thus, 4 is how the present author characterized Parnes's "Creative Behavior Guidebook".

tures and handout material he describes Polya's four step procedure and enriches the presentation from Wickelgren's ideas. Then the students, in groups of three or four, solve problems and report to the total class how they solved the problem. This activity is the introductory part of a course in mathematics.

Wallach [13] for senior level courses, provides 16 sequential sets of references in an area of psychology. These sets trace the development of the research ideas. From this the students learn how to analyze the research literature and to design experiments. At the end of the students' study of these selected case histories, each student prepares a research proposal.

Richards [14], in a freshman engineering laboratory, requires that the students devise their own experiments to discover ideas. Sample problems include discovering the optimum closure time of wire-wound mousetraps, and the factors that affect the time it takes staved-in boats to sink. More details are available from his Nuffield Foundation report.

Small [15], in an immunology program poses clinical problems to the class. As a group they analyze the observations, formulate an hypothesis, design experiments to test these, interpret the data and decide if the hypothesis is confirmed.

Walters [16] has several noteworthy approaches. The first uses broadly defined problems in computer programming. For example, students are given the following data for 30 people: name, social security number, weight, height, date of birth, etc. They first prepare instructions as to how to keypunch these data; second they keypunch the data following a fellow student's set of instructions; third they keypunch the data following the instructor's instructions. Each state is evaluated: what they do differently in their own work, and problems they discovered in other people's work. Many other projects follow this pattern. The emphasis is on the method. The students learn by seeing an example, then doing it themselves and then benefitting from comments of others during group discussion of the solutions and methods of solution with computer program as media. The second course, on clinical skills, uses many of the same learning ideas. The emphasis is on developing alternative causes of clinical symptoms and the generation of an hypothesis. Computer simulations are used for some of the cases. The students are video taped while they are solving the problems.

Powers [17] is a co-author of a very imaginative text that has done much to organize the strategy and criteria used for designing chemical plants [9]. His own courses and emphasis are on computer-assisted problem solving and some of the work of Newell and Simon [18] [19]. In his case study approach he uses the state space, decomposition and theorem-proving representations of the problem. His review [20] summarizes these techniques.

Douglas and Kittrell [21] has developed an imaginative course on entrepreneurship. The emphasis is on idea generation and exploitation, screening ideas and problem and program definition. They suggest a 12 step strategy. The case studies provide much practice in taking problems apart and in having the students ask the right questions. Some example case studies include the manufacture of maple syrup in the home, and the development of cigarette filters.

King [22] uses a wide variety of learning environments in his courses on engineering synthesis: teacher poses series of discussion questions, large and small case problems worked by students individually or in groups, simulations, and trouble-shooting problems [23]. Many case study problems have been developed [24]. Classroom activities include brainstorming and other creativity fostering activities.

Shields [25] emphasizes the application of Kepner and Tregor's [26] problem solving algorithm as part of a course on management and decision making.

Our effectiveness in teaching problem solving skills by this approach depends very much on the consistency and detail presented when examples are worked in class, the faculty-student dialogue during that example, the type of homework assigned, the way the question is asked . . .

In Fuller's [27, 28, 29] Process Principles Course the students compose, choose and solve a series of case problems. His approach is based on Maier's ideas [30]. The experience for the students include choosing point of view or identification in the context of a case, composing problems based on the situation, assessing values of the composed problems, choosing the most valuable problem to try to solve, sorting out information relevant to the problem, proposing potential solutions, evaluating and recommending action.

GUIDED DESIGN

WALES AND STAGER in their text "Educational Systems Design [31]" make telling arguments for the use of guided design as part of a curriculum. They have followed this with their text (which they coauthored with Long) entitled "Guided Engineering Design" [3]. The flavor of the text is engineering but the applications can be broad.

Of the respondees to the questionnaire, three center their course around this approach as is shown on the top central section of Figure 1. Swartman [33] uses this text for small group tutorials and complements this with a series of lectures on the elements in solving problems: decision making, creativity, problem solving strategies, project management and communication skills.

Stager's [34] course stresses five elements: modern techniques for problem solving, morphology of design, effective communication, criterion function and effective learning. Case projects are solved by teams. Projects include problems on noise and water pollution and on the suspension system for an automobile. He has special activities on group selection and dynamics, brainstorming, problem recognition and synergistic decision making.

Wales, Pappano and Bailie [35] have extended this open ended problem solving approach to other courses so that much of the four year curriculum at West Virginia contains elements of this approach.

CASE STUDIES AS CURRICULUM CORE

THIS APPROACH IS SHOWN by the top central area of Figure 1 around reference 3. The approach is different than those in section 2.3 mainly in committment. The engineering school at West Virginia is moving toward orienting major portions of their curriculum to case studies or what could be called problem-based learning. The McMaster Medical School [36] was founded around this concept. The three year medical program uses a series of carefully selected problems. The students learn by solving these in groups of three to five students. For each problem the students decide the questions they want to ask, they identify issues or themes, generate alternatives, (ranging from the submolecular structure level to the social structure level), decide on one alternative and look for the variety of experience available, gather information, resolve the issues and evaluate. Each student group has a tutor and many resource persons available. In addition, self-paced learning packages have been developed for all the background knowledge needed in the three year medical program. The problems are posed via paper descriptions, problem boxes, simulated patient, protocol card game (The P_4 game), actual patient, or computer simulations.

Very complete and stimulating series of papers and reports are available that describe the approach and provide background on such topics as how to be a small group tutor and developing case studies (problem boxes or the P_4-game).

A simulated problem-solving tutorial is part of the admissions tests to gain entry into the program. No formal programs on how to solve problems are given. The emphasis is on the tutor and the small group tutorial. Continuous assessment is used for the students, the tutor, the case problems, the resource materials and the program. More details are available [37, 38, 39].

Some approaches, shown on Figure 1 near the bottom right hand side, emphasize the elements of problem solving. Fuller [27] blends Polya [5] diagrams with the content of his chemical reaction engineering course. His emphasis is on changing students' perceptions of problems (as opposed to memorizing strategy or sequence of activities) so that they see problems as a set of elements and a structure that makes the solution routine. The ideas are based on Polya maps and Newell and Simon's 'problem space.' The course is PSI with students asking questions about the analysis of the problem statement, the structure of the problem, the composition of a new problem having the same structure and the composition of a new problem having a structure related to the given one. Trouble-shooting (diagnostic) case studies are used as well as his own special story

The engineering school at West Virginia is moving toward orienting major portions of their curriculum to case studies or what could be called problem-based learning.

case problems. More details are available [28, 29].

Brown [40] presents the content of his introductory course in Mechanics uniquely. About the first one third of the course introduces the basic laws—the knowledge that is to be applied. The last two-third is centered around solving problems, and showing the inter-relationships among the laws. This latter activity is centered around the Polya map. Throughout the course there is an emphasis on developing the students' ability to analyze situations.

Black [41] has an extremely imaginative skills tutorial to complement freshman physics courses. In this tutorial, groups of four students solve problems together and then combine with four other such groups to discuss the ideas generated and to share experience. Each set of problems has some open-ended real world problems and some related directly to the physics course. The topics for the sessions are—estimating orders of magnitude, scaling, translation: graphical-verbal, translation: algebraic-graphical, words into symbols, the art of negligence, using algebra in an argument, planning an investigation—first steps, designing apparatus, designing an experiment, "design consultants," thinking of alternatives, think about it first, what's the principle?, physical intuition, when is it true?, seeing the key, what are the relevant variables, spotting the fallacy, and 'bugs.'

Although more information is available from Black et al [42] details of the tutorial package are described in the HELP(P) material [43].

Rubinstein's [44] course on problem solving is relatively independent of the discipline. The flavor of his approach can be seen from his recent text Rubinstein (1975) which provides us with a good survey of especially the elements in problem solving such as semantics, probability, models and values.

Reif et al. [45] and Larkin [46, 47] have focused on two aspects of problem solving. A problem-solving strategy (description, planning, implementation and checking) was explained to the students, and its use demonstrated. Then, the students were given practice and feedback on their application of this strategy to solve their homework problems. The second aspect of problem solver's ability to select and apply the correct basic knowledge needed to solve the problem. They discovered that experienced problem solvers use fewer relationships or equations to solve problems than do the inexperienced problem solvers. Hence, the students are encouraged to ensure that they see how all new ideas, laws and definitions relate to their previous knowledge. To assist them worksheets have been developed that the students complete for each new concept. More details are available [45, 46, 47].

STRATEGY EMPHASIS

IN THIS CATEGORY are some noteworthy and completely different ideas on teaching course on problem solving where the emphasis tends to be—to varying degrees—on the strategy.

King uses a wide variety of learning environments in his courses on engineering synthesis: teacher poses series of discussion questions, large and small case problems worked by students individually or in groups, simulations and trouble-shooting problems.

Spark's [48] approach is as a credit, pass-fail freshman course. The students and professor get excited together by solving sets of problems. The sequencing and objectives for each set are well defined and well selected, with emphasis on building confidence, being able to generalize and to recognize unwarranted assumptions. The students must begin to see the value in *any* answer. An example of the topic is:

- **What can I do with it? Here the students are given a blob of magnetic plastic and asked this question.**
- **What does it mean? The students must discover ideas about mixing, and design a large scale process from observing the mixing of cold chocolate syrup into milk. I found the ideas and concepts exciting but would find it difficult to mount a complete program such as this because I felt I lacked Spark's experience and depth in the technical subject. More details are available [49].**

Others might find Magazine's [50] approach easier to implement for the first time. Like Sparks, the idea is for the group to solve a carefully constructed sequence of problems. However, Magazine asks colleagues to be part of the experience and, as resource persons, to pose problems for the group. A larger consulting type problem is selected from a local industry. Examples include how to mark off a parking lot, redesign a typewriter, nutrition of growing insects, the process of plea bargaining, patient transportation in hospital, and the optimum mix of ingredients in sausages. Both Sparks and Magazine use the contact time with the students to solve problems together.

Two other variations on this theme are described by Eastburn [51] and Barker [52], although they seemed to have a stronger lecture component to them. Eastburn's emphasis is on a five step strategy and on creativity with a special effort to give the students a personal awareness of their capabilities, while Barker hopes that through case studies students will identify what problem solving techniques and steps can hinder creativity.

Some courses that are more structured are described by Wickelgren [53], Wheeler [54], Stonewater [55], Slaymaker [56], and Liddle [57]. Polya [5] has influenced the approaches of Wickelgren, Stonewater and Wheeler. Wickelgren [53] has enriched the Polya work by introducing artificial intelligence ideas from for example, Newell and Simon [18]. His attractive text [6] is a very welcome outgrowth and enrichment of these two approaches and his emphasis is on solving problems (as opposed to talking about it). The problems used are mainly recreational mathematics.

Stager's course stresses five elements: modern techniques for problem solving, morphology of design, effective communication, criterion function and effective learning Case projects are solved by teams. Projects include problems on noise and water pollution and on the suspension system for an automobile.

Wheeler [54] uses Wickelgren's text [6] and combines it with topics on thinking, decision making and communication. His course is organized into nine units. The unique emphasis is that the students discover what methods they use when they solve problems, and they get experience applying the methods more appropriately and efficiently. They become aware of a strategy for solving problems. His units are:

- Introduce groups and discover how to solve problems. NASA problem.
- Listening skills.
- Making assumptions.
- Trouble with words and definitions.
- Problem analysis—drawing trees, logical inference, concept or hypothesis formation.
- Methods for detectives—examining evidence, brainstorming, eliminating alternatives.
- Decision making—developing balance sheets, value clarification, intuitive decision making, decision counselling.
- Putting it all together—synectics.
- Evaluation.

Stonewater [55] has prepared a self paced program on problem solving. His units have the Polya-Wickelgren flavor. There are three packages to the seven units: Preparation, Communication and Strategies. The details are:

- Preparing for Problem Solving (1 unit) — (problem definition, list criteria, identify given information, and summarize as problem statement).
- Communication and Clarification (2 units) — (drawing diagrams and preparing tables).
- Strategies (4 units) — (subproblem, contradiction, inference and working backwards).

His imaginative problems are mixtures of puzzles, short mathematical problems and science/engineering homework problems.

At Alverno College, the focus is on eight abilities in their competence—based learning program that is an integral part of their program [58]. These abilities are in communication, analysis, problem solving, value judgments and decision making, social interaction, interrelating between the individual and the environment, between the individual and the world in which ones lives and between the individual and the arts/humanities. For problem solving six levels of achievement are identified that range from identification of the process (level 1) to demonstration that problem solving is an assumed approach in one's own search for knowledge and one's reflection upon experience (level 6).

Slaymaker's [56] course requires the students to record their behavior and thoughts as they solve several laboratory problems. This is used as background for a survey of theoretical models of problem solving and thinking.

Finally, Liddle [57] has offered a course on problem solving to engineers and managers in industry. His approach is influenced by Raybould and Minter [59]. He emphasizes three phases: diagnosis, exploration and evaluation.

This group of approaches is shown on the upper right of Figure 1.

THE METHOD OFFERED

TO TALK ABOUT METHOD separate from the content is difficult and can be misleading.

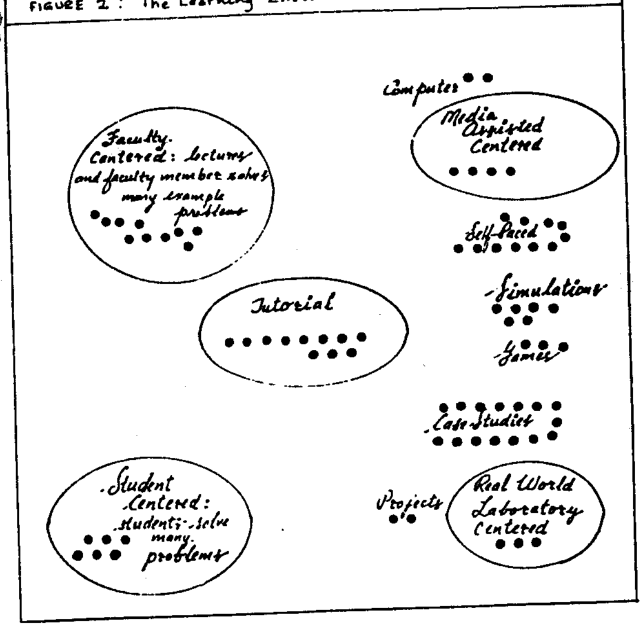

FIGURE 2 : The Learning Environment Used.

Yet, such a classification does identify groups that are using similar methods. Figure 2 shows the type of learning environment used. This figure shows five focal points—the faculty member as a lecturer or example problem solver, the students who work many assignments on their own, the tutorial where students and tutor work problems together, the media assisted environment and the "real world" of hardware. Most approaches combine the possibilities. Noteworthy features to me were the extent of the use of group problem solving, especially the small group tutorial, the use of computers and self paced material and case studies.

To solve problems we must have problems to solve. What type of problems are being used? The respondees used a wide variety of problems. Some used ordinary homework problems, some posed problems that are open ended (or divergent) which require the solver to generate many alternative "good" solutions and to select the "best," some want critical-instant type problems, and some would like to use everyday problems. The variety includes technical problems in our physical world (devoid of having to worry about how people react), technical problems where people are part of the problem (such as biologically medical problems or process plant problems where the operators are part of the problem), people problems, everyday problems and mathematical puzzles. No general advice about the choice of problem could be discovered.

Some asked that the problems be solved by groups of students working together, others by individuals or by a mixture.

Finally, those separate courses on problem solving can be either solving general problems or clinical/design problems. For these courses, the size of the class or tutorial was usually less than twenty.

SUMMARY

To try to discover what we at McMaster University might do to improve the problem solving, we asked over 1000 departments to describe how they teach problem solving. The responses showed a wide range—some work many sample problems in class, and some have a separate course on problem solving; some emphasize the overall strategy, and some, the steps in that strategy. This variety was summarized as a graph and from this, six general characteristics could be identified. These were experiences with the emphasis (1) on the discipline, (3) on guided design, (4) on case studies as a core for a curriculum, (5) on problem solving (the steps) and (6) on problem solving (the strategy).

The learning environment, the types of problems and how they were solved, the variety of approaches used—were summarized. □

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ON TEACHING PROBLEM SOLVING

Part II: The Challenges

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A SURVEY OF HOW various individuals or institutions teach problem solving skills has been reviewed [83]. What are the challenges or difficulties encountered in trying to improve a student's skills in solving problems and what are some ideas for overcoming these challenges?

The overall challenge in general is well described by Hilko [60]†, a student from University of Waterloo, and by Hupert [61], a professor from De Paul University. Hilko says that using problem solving to test or give practice in knowledge gained does not necessarily give training in how to think. The need is to provide formal descriptions of problem solving, the strategy and the elements therein, so as to make explicit what many have learned consciously or subconsciously and emphasize universality of approach. Hupert comments that there are two sides to every academic discipline: (a) knowledge and (b) skill (including problem solving). An academic course which does not handle both sides is a half-baked enterprise and does not fulfill its objective.

The specific challenges according to the respondees are a mixture of four:

- **difficulties with students' backgrounds, abilities and attitudes, (the prerequisites),**
- **difficulties with the subject,**
- **difficulties students have with the subject of problem solving,**
- **difficulties instructors have in teaching it.**

Each is discussed in turn.

†References continue from those given in Part I [83].

BACKGROUNDS, ABILITIES AND ATTITUDES

IN PART I, I tried to limit this survey to those efforts being made to improve problem solving and not those to improve the host of prerequisite skills. Yet, here we must face any difficulties students have with the prerequisites. The respondees said that the students

- **are weak in the basic technical knowledge(scientific or medical)**
- **lack elementary skills in logic (do not draw appropriate conclusions from the information they have, and cannot correctly reason deductively,**
- **are weak in communication skills,**
- **have acquired bad habits for solving problems, or do not recognize that they have any problem solving skill. (This was expressed as 'we expect to acquire problem solving techniques somewhere, but they don't, students jump in and follow a gut feeling instead of taking a more systematic approach, students do not examine alternative strategies or cannot think up alternatives students are not aware of what they are doing when they solve problems),**
- **lack the motivation. (This was expressed as 'the students won't grasp opportunities to improve themselves and they want to collect type problems instead of applying basic knowledge to solve new situation problems on their own),**
- **fail to recognize that problem solving in itself is a legitimate educational goal,**
- **do not emulate good problem solving.**

Some difficulties are training and convincing faculty that problem solving is in itself a legitimate educational goal. As a personal aside, just about everyone thinks that they "teach problem solving"; everyone is an expert. If one tries to do something about teaching problem solving skills, then we must be prepared for a wide variety of comments. Some ask "Who is he that he thinks he knows how to teach problem solving?" Some say, "It can't be taught." Some say "Everyone's doing it so why make a big deal out of it?" Another difficulty is in identifying or specifying an algorithmic approach for each strategy that identifies the discrete skills and behaviors to be performed. Respondees said it was difficult to identify the necessary skills and to test for them. And last they found difficulty in convincing students that the extra effort required to learn a procedure or new terminology (such as a meta language) is worth the effort.

PROBLEM SOLVING STRATEGY

THERE ARE A HOST of different listings of the steps that make up the overall strategy for solving problems. Some of these are listed in Table 1. Some respondees identified the steps or activities that gave the most difficulty to be:

- subsystem identification and relationships among the subsystems,
- relating subsystems to theory and the question asked,
- translating physical problem into a mathematical description,
- simplifying complex problem or making good assumptions,
- being creative,
- asking general questions first; asking specific questions later,
- creating a hypothesis,
- how to ask the right questions,
- anything to do with analysis.

more specifically as difficulty in posing problems so that students develop understanding of general principles and general problem solving strategy rather than memorizing solutions to specific "type" problems; posing problems appropriate to students' skills and sufficiently modest to enable the student to have adequate success with them, and finding the time required to prepare good problems,

- to find the time to prepare the lecture notes, the problems or other materials; It is interesting that most have developed their own set of notes or problems.
- to get students to see the underlying problem solving process

CONCERNING THE METHOD

Teaching problem solving offers challenges in the area of method.

The challenges cited are:

One challenge cited was keeping the course interesting and moving especially after the students realize that they are not going to get answers to all their real life problems.

Challenges as discussion leader include:

- pacing the discussion so that all participate,
- structuring the discussion so that all see a logical structure,
- not overstructuring the problem solving learning situation,
- knowing when to intervene and when to let the students go out on a limb,
- controlling the sessions, keep the group on track and to prevent students from bringing in personal problems for the other students to solve,
- as an instructor, avoiding philosophizing and lecturing, but to set the ground rules,
- not squashing creativity,
- as an instructor, refraining from becoming part of the problem or of the solution,
- knowing when to stop because the problem is giving diminishing returns for learning about problem solving; especially when they want to continue brainstorming,
- getting effective groups that work together and where everyone participates.

Another challenge involved in the methods of teaching problem solving is to give the students sufficient practice that they have confidence in applying a problem solving strategy and to get

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Most of the challenges listed by the respondees concerned how to teach it. One needs to overcome the reluctance of instructors to give such an open-ended course, to try to describe how they solve problems, to try to solve problems they have not seen before and when they might fail. One should get the experience into the curriculum at the right time, or to match the education program with problem solving strategies used in actual practice.

Some of the difficulties given by the respondees in regard to content preparation are listed below.

- to locate a good text that is acceptable by the students, or to locate good resource people,
- to get good problems to work on. This was described

TABLE 1: SOME STRATEGIES FOR SOLVING PROBLEMS

D'ZURILLA & GOLDFRIED[2]	BLOOM & BRODER[74]	WALLAS (1926) [see DAVIS[1] p.16]	KINGSLEY & GARRY (1957) [see DAVIS[1] p. 16]	DOUGLAS[21]
1. General orientation (recognize problem exists & be positive in approach)	1. Understand nature of problem	1. Preparation	1. Difficulty felt	1. Idea generation or indentify problem
2. Problem definition & formulation	2. Understand ideas contained in problem	2. Incubation	2. Problem clarified & defined	2. Initial screen
3. Generation of alternatives	3. Procedures used	3. Inspiration	3. Search for clues is made	3. Complete the problem statement & define critical steps
				4. Translate
				5. Sketch a diagram
				6. Sketch to guess better answer
			4. Various suggestions appear & are tried tried out	7. List assumptions & try simplest analysis
4. Decision making			5A. Suggested solution is accepted	8. Estimate solution
5. Verification	4. Attitudes toward the solution	4. Verification	6. The solution is tested	9. Evaluate & explore implications

POLYA[5]	WOODS et al[81]	RICHARDS[14]	SMALL[15]	AUBEL[82]	EASTBURN[51]	FULLER[27]
1. Define	1. Define	1. Identify objectives	1. Observe/ gather information	1. Set up problem	1. Fact finding	1. Choose point of view
					2. Problem finding	2. Compose problem
	2. Think about it	2. Identify important variables	2. Formulate hypothesis	2. Analysis: physics	3. Idea finding	3. Assess composed problem
2. Plan	3. Plan	3. Use dimensional analysis				4. Choose most valuable problem to try to solve
		4. Identify apparatus to be used	3. Design test	3. Analysis: math		5. Sort out information
		5. Plan tests				6. Propose potential solutions
3. Carry out the plan	4. Carry out the plan	6. Plan data recording activities	4. Interpret data		4. Solution finding	
		Interpret control curves	5. Is hypothesis confirmed?		5. Acceptance-finding	7. Evaluate
4. Look back	5. Look back	decide how results should be reported, what results mean ask "is test finished?" "am I finished?"				8. Recommend action

STAGER[34]	MAGAZINE[50]
1. Recognize problem	1. Problem formulation
2. State basic objective	2. Data collection
3. Gather information	3. Abstraction
4. State constraints, facts assumptions	4. Quantitative model
	5. Deduction
5. Generate possible solutions	6. Analysis
6. Evaluate and make decision	7. Interpretation
7. Analysis, synthesis & evaluation of solution	8. Data collection & verification
8. Report results & recommend action	

the students to translate a problem solving skill from one problem to another, or from a problem solving course to their "other" courses, or from academic problems to their personal problems. There is also a challenge to provide consistent information to each group (when having many groups doing the same problem).

Two challenges in evaluation are: measuring and evaluating student performance; and evaluating what we have done.

IDEAS FOR THE FUTURE

HERE ARE SOME ideas for discussion based on the responses summarized in this report.

Small group tutorial—The advantages of the small group tutorial as a means of teaching problem solving seem to have been emphasized. If this is the way for us to proceed then for the large introductory classes, this required a large faculty commitment and good tutors. Is there any other way we can achieve these advantages? or can we afford to take this approach or perhaps; can we afford not to?

Everyday homework base—Many seem to have imaginative courses for solving the large open-ended problems. Have we provided sufficient basis for good problem solving habits for those students entering such courses? Are the students learning anything about problem solving from the usual everyday assignments? What should or could be done to provide students with good habits for solving the everyday assignments?

Overcoming learning skills deficiencies—Many students are not proficient at self learning or at collecting and evaluating information for themselves. They have difficulty identifying the key ideas of knowledge nor can they see how these ideas are interrelated. These are necessary prerequisites to being good problem solvers. When and how can these be taught?

When—Those who have a special problem solving emphasis in the more senior years get student response: "we wish that we had this sooner." When should different elements of problem solving be taught? What should the relationship be between the university and college and the high school programs?

Translation of skills—Those who have courses primarily on problem solving find that the students have difficulty translating what they have learned to other courses and situations. How can we overcome this problem?

Communication—The literature on problem solving and creativity is extensive, and it is difficult to discover resources that are pertinent to individual needs. Some references have been listed in the bibliography. Some additional resources that might be useful include:

- **In the area of engineering design:**
  Jones [62], Dixon [63], Krick [64], Asimow [65] and Buhl [66].
- **In the area of mathematics:**
  Jenson and Jeffreys [67], Chapter 1 and especially p. 21, and Himmelblau and Bischoff [68], Chapter 1.
- **In the area of business:**
  Achoff [69], Two very interesting little example books are the UNESCO publications, Servais and Varga [70] and Lewis [71].
- **In the area of puzzles:**
  Fixx [72] and Sobol [73].
- **In the area of thinking and problem solving:**
  Bloom and Broder [74], Buzan [75], Survival Problem [76].

Despite the apparent differences in discipline and in approach there are great similarities in the types of problem and in the method of solving it. A challenging question is how can those interested in teaching problem solving maintain contact and share ideas?

Some difficulties are training and convincing faculty that problem solving is in itself a legitimate educational goal. As a personal aside, just about everyone thinks that they "teach problem solving"; everyone is an expert.

SUMMARY

The challenges to presenting a course in problem solving cited by the respondees were summarized as difficulties with the student's background, with the subject, with the student's understanding of the subject and with teaching it.

Some suggested follow up questions are posed and some answers given.

As a postscript, at McMaster we are complementing this survey with a four year experiment to try to discover specific approaches that we should take to improve our student's ability to solve problems. This work is described elsewhere [79, 80, 81].

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