ChE classroom

PUTTING PROBLEM SOLVING TO USE IN THE CLASSROOM

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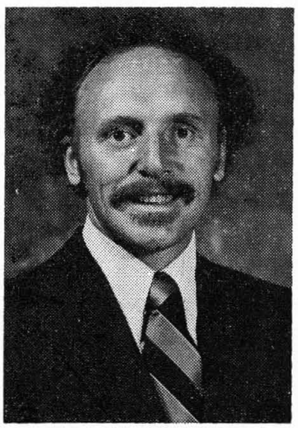
PROBLEM SOLVING HAS become an area of intense interest and study [1-10]. Textbooks have been written on the subject and separate courses are being offered. While it would be impractical for all engineering educators to attempt separate offerings in problem solving, the concepts and application of problem solving can be utilized in existing courses. This can be done without any loss of material coverage.

The objective of this paper is to indicate specific areas in a course being taught where the problem solving approach can be utilized and why this approach can be useful.

BACKGROUND

There are a large variety of problem solving strategies but most contain the elements initially described by Polya [11] and expanded by Woods [1]: 1) Define the problem, 2) explore possible solution procedures, 3) develop a solution plan, 4) carry out the plan, and 5) check your results. This is often not a straight linear process since the problem solver may have to loop backwards at any stage of solution process to redefine the problem or develop new solution strategies if the initial attempts fail. The degree of difficulty in solving problems can be related to the level of difficulty outlined in Bloom's taxonomy of knowledge [12] (see Table 1). As problems require higher levels of thinking, students experience increased difficulty since they have had little or no practice in problems at higher thinking levels. Most problems at the end of a chapter in an engineering textbook require application. Problems requiring analysis and synthesis are rarely encountered by students. Once encountered, students have no structured process for solving these problems. Even problems requiring application of material presented can be difficult. Students expect exactly the right amount of information given to solve the problem and a definitive statement of what the problem requires for a solution. Even at this point, if students cannot plod straight through to the solution, they sometimes become confused and cannot develop a solution. Overcoming anxiety and frustration then also becomes an important component of problem solving [13, 14].

This paper will present a series of different approaches which can be used with a class to develop their problem solving skills. These techniques require some time and effort to implement.



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LEVEL OF PROBLEMS ASSIGNED

Refering to Bloom's taxonomy (Table 1), most problems at the end of a textbook chapter or on an examination require application. Typically, the exact amount of information required to solve the problem is given and the student applies knowledge learned in the chapter to the problem. Higher levels of thinking such as analysis and synthesis, are normally not encountered. Therefore, students get no practice in applying newly learned knowledge as part of a more complicated or vague problem.

To overcome this limitation, a mixture of problems requiring application, analysis, and synthesis will reinforce a student's learning and use of this knowledge in expanded situations. This will require some additional work on the part of the instructor since development of analysis and synthesis problems would be required.

TYPE OF EXAM QUESTIONS

The type of question given a student on an examination can certainly put to use the problem solving skills of the students. Using problems which just require comprehension or application do very little to test the student's problem solving skills as well as knowledge. Adding a problem which requires analysis provides the framework for students to make better use of their problem solving skills since the degree of difficulty increases. This is not to say that solving problems requiring comprehension or application do not make use of problem solving skills but adding more difficult problems can increase a student's problem solving skills. If we test students on problems requiring analysis or synthesis, it is important that we have provided some prior practice in solving problems at these thinking levels.

TABLE 1
Bloom's Taxonomy of Knowledge

Knowledge—Recall memorized information.

Course	Laboratory
What is Fourier's law of heat conduction?	Measure velocity of fluid in a pipe at five points along the cross-section.

Comprehension—Solve recognizable problem.

Course	Laboratory
If the temperature gradient through a plance wall is tripled, what is the resulting change in the heat flux?	Compare the measured velocity distribution with laminar flow theory.

Application—Use memorized knowledge to solve unfamiliar problem.

Course	Laboratory
What is the steady-state heat flux through a composite wall, given k's and boundary temperatures.	Determine the relevant data needed to test the laminar flow theory in pipes.

Analysis—Bring together remote relationships to solve problem.

Course	Laboratory
A fire breaks out in a room adjacent to a fuel tank. How long before the fuel explodes?	Determine why the experiment for flow through a pipe does not agree with laminar flow theory.

Synthesis—Create alternative solutions to an open-ended problem and select best one.

Course	Laboratory
Design a heat exchanger. Specify type and construction details.	Design an experiment to measure the velocity distribution in pipes.

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EXAMPLE PROBLEMS IN CLASS

The use of example problems can serve as a tool for developing problem solving skills as well as knowledge. All aspects of a problem solving strategy can be utilized in an example problem. Once the problem statement is read from the text or hand-out, I ask the class to determine the given facts, what we are asked to find, and draw a diagram. Once this is completed, I ask the students to provide the solution steps. If a step is incorrect, we will still follow it until the class realizes that something is wrong. This shows students that it is OK to make a mistake, a common emotional block to creativity. By testing each solution procedure, we can determine errors in reasoning and also show alternate solutions. We check our results at each step in the process to determine the reasonableness of our answer. Different heuristic techniques can be utilized with different example problems to aid in the solution process [15] (see Table 2 for examples). Students can be asked to provide heuristics. Another approach is to try at least one new heuristic each week in class. Once the solution is obtained, the answer is checked to insure reasonableness and accuracy. If difficulty arises at any step in the process, this is the time to let the students loop back through the process or use heuristics to become "unstuck." Once the solution is complete, I ask the students questions which relate to the problem to increase their understanding. Which variable can we control? What happens to the solution if various variables are changed? It may be necessary to guide the students in this process. As their skills develop, the guidance can be reduced.

TIME FACTOR IN EXAMINATIONS

One key aspect of problem solving is the realization that people usually do not progress directly through a solution process to the answer. There can be false starts, redefining the problem, alternate solution paths, and finally, checking the answer. The point of this is that people need sufficient time to allow the problem solving process to be fully utilized. By assigning difficult problems and allowing a relatively short period of time for the student to respond, the student can be placed in a high anxiety situation where his performance will be low. One method to deal with this problem is to allow two hours for a one hour examination. If a student makes a mistake, this allows sufficient time to recover and proceed through to a proper solution. My experience has been that students will respond very well to taking evening exams with the extra time allotted.

Engineering problems, especially in junior and senior level courses, require more than a few minutes to complete a good solution procedure. Allowing the extra time allows the instructor to assign problems requiring analysis instead of just application.

TABLE 2
Some Heuristics or Guides

1. **Solve a simpler problem.** Many times a student can become immersed in a complicated problem and become "stuck." Simplifying the problem to a stage where the student recognizes the solution approach can aid in developing the actual solution procedure.
2. **Overcome excess anxiety.** When a student becomes "stuck," they can develop a large amount of anxiety which prevents effectively developing a solution. Awareness is the first step to combating this.
3. **Communicate your difficulty to another person.** It is sometimes very beneficial to try to explain your situation to another person who is familiar with the subject. Describe what you have done and what you are trying to do. Often this will help to point out additional informaton or errors in reasoning.
4. **Brainstorming.** When "stuck" on a problem, generate a list of words or phrases which immediately come to mind. Write everything down and defer judgment until you have exhausted the flow of information. Once this is completed, analyze the list and use judgement to determine any new relevant information.
5. **Personal analogy.** Pretend that you have entered the system under study. Try to imagine what you see, feel, etc. This helps to "visualize" the situation.
6. **Look at extreme cases.** Ask yourself a lot of "what if" questions to get a "feel" for how you think the system will respond. Have will to doubt. Focuses attention on different aspects of problem.
7. **Incubation.** Sometimes it is helpful to stop actively working on the problem when "stuck." Let the problem "incubate" for awhile. Some insight may "pop up" into your conscious domain or, upon your return to the problem you can see errors in reasoning or other obstacles to the solution that were not previously obvious.

GRADING

The method that you use to grade exams and homework problems can influence a student's problem solving behavior. If the major credit is given for a right answer, a student will become mainly concerned with the answer and not the solution process. If a student stops getting credit as soon as he or she makes a mistake, they can develop a great deal of frustration and anxiety. Fear of making a mistake is an emotional block to creativity. They lose perspective on the problem solution and deal mainly with frustration. If the student receives the major portion of credit for a proper solution, the student will work at developing a correct solution without a high degree of anxiety over making a mistake.

HELP OUTSIDE THE CLASSROOM

If a student comes into your office for assistance, it is very easy to simply show them how to do the problem and have them leave. A more effective technique would be to help them work through the method of solution. Whimbey and Lockhead's problem-solving pairs is one example [4]. By guiding the student but not giving them the answer, you help them not only to solve the problem but to develop problem solving skills along the way. Wankat [16] and Miller [17] describe some useful approaches in talking with students that could prove helpful in these situations.

BEHAVIORAL OBJECTIVES

The use of instructional objectives in a class can be a major asset to problem solving. Outlining the major concepts and explaining what is required for a particular topic gives the student a framework for developing a solution strategy. Instructional objectives can also include such items as ability to check reasonableness of an answer or the ability to develop an alternative solution procedure. Mager's book [18] is an excellent source to learn about using instructional objectives.

There are also additional references concerned specifically with instructional objectives for engineering classes [19, 20].

CONCLUSION

The use of problem solving skills in various class situations has been discussed. It has been shown that the thinking level of assigned problems, type of examination questions, example problems in class, time factor in examinations, grading, help outside the classroom and behavioral objectives are all areas where problem solving skills of students can be incorporated. This allows the class experience to be one where both an increase in knowledge and problem solving skills can be attained. □

REFERENCES

1. McMaster University Problem Solving Group, "Development Stype in Solving Problems," Engineering Education, Vol. 69, No. 7, April, 1979.
2. Greenfield, L. B., "Student Problem Solving," Engineering Education, Vol. 69, No. 7, April, 1979.
3. Rubinstein, M., "Patterns of Problem Solving," Prentice-Hall, Inc., 1975.
4. Whimbey, A. and J. Lockhead, "Problem Solving and Comprehension: A Short Course in Analytical Reasoning," Franklin Institute Press, 1980.
5. Adams, J. L., "Conceptual Blockbusting," W. W. Norton and Co., Second Edition, 1979.
6. McMaster Problem Solving Group, "What is Problem Solving," Chemical Engineering Education, Summer 1979, pp. 132-137.
7. Woods, D., "On Teaching Problem Solving, Part I: What is Being Done?" Chemical Engineering Education, Spring, 1977, pp. 86-94.
8. Woods, D., "On Teaching Problem Solving, Part II: The Challenges," Chemical Engineering Education, Summer 1977, pp. 140-144.
9. Noble, R. D., "Mathematical Models in the Context of Problem Solving," Mathematical Modeling, Vol. 3, 1982, pp. 215-219.
10. "Problem Solving," AIChE Symposium Series, Edited by D. R. Woods, J. T. Sears, and R. D. Noble, 1983.
11. Polya, G. "How to Solve it," Second Edition, Doubleday Anchor, 1957.
12. Bloom, B. S. and L. G. Broder, "Problem-Solving Processes of College Students," Supplementary Educational Monographs, No. 73, Univ. of Chicago Press, 1950.
13. Richardson, S. A., R. D. Noble, and M. Hawkins, "The Use of Relaxation in Overcoming Anxiety in Problem Solving," Engineering Education, Nov. 1980.
14. Richardson, S. A., and R. D. Noble, "Anxiety: Another Aspect of Problem Solving," AIChE Symposium Series on Problem Solving, 1983.
15. Schoenfeld, A., "Explicit Heuristic Training as a Variable in Problem Solving Performance," J. for Research in Mathematical Education, May 1979.
16. Wankat, P. C., "The Professor as Counselor," Engineering Education, November 1980, pp. 153-158.
17. Miller, P., "Nonverbal Communication: How to Say What you Mean and Know What They're Saying," Engineering Education, November 1980, pp. 159-161.
18. Maker, R. F., "Preparing Instructional Objectives," Fearson, 1962.
19. Leuba, R., "Instructional Objectives—A Guide to Effective Teaching," American Society for Engineering Education publication, 1980.
20. Stice, J., "A First Step Toward Improved Teaching," Engineering Education, Vol. 66, No. 5, Feb. 1976, pp. 1-5.

ChE book reviews

FUNDAMENTALS OF MULTICOMPONENT DISTILLATION

By Charles D. Holland
McGraw-Hill Book Company, NY

626 pgs, $39.95

Reviewed by
William L. Bolles

Monsanto Company, St. Louis, MO

This book may be regarded as the "Bible" on calculating the detailed mass and energy balances on a plate-to-plate basis for distillation columns processing multicomponent systems. It may also be regarded as the prime textbook for those writing computer programs for the same.

The book is intended to completely replace the 1963 volume by the same author, entitled "Multicomponent Distillation".

The principal problem attacked is achieving the complete component mass and energy balances for the "complex distillation column": i.e., one with multiple stages, multiple feeds, multiple sidedraws, either liquid or vapor, and multiple stage heat exchangers. Also, it is assumed that any multicomponent nonideal phase equilibria and enthalpy models may apply. The approach is rigorous insofar as the Frst Law of Thermodynamics is concerned.

The author develops his subject in a very orderly manner, including the following major topics: introduction to the fundamentals, development of computational convergence methods, application of convergence methods to complex columns, systems of columns, the Newton-Raphson method application, azeotropic and extractive distillation, systems of columns with energy exchange between streams, distillation accompanied by chemical reaction, optimum design and operation,