PROBLEM SOLVING

Most of the literature on problem solving views a "problem" as a gap between some initial information (the initial state) and the desired information (the desired state). Problem solving is the activity of closing the gap between these two states. Of course, not all problems have a solution. Problems are often classified as (1) "**open ended**" vs. (2) "**closed ended**." The former means that the problem is not well posed and/or could have multiple solutions. The latter means that the problem is well posed and has a unique solution. At the end of each section in this book you will find open ended discussion questions and thought problems, but all of the examples and the bulk of the problems in this book are closed ended--short, simple, and packaged with precisely the information needed, unlike those that occur in real life.

If you are going to become a professional, you will have to acquire a number of skills in problem solving such as:

- formulating specific questions from vaguely specified problems;
- selecting effective problem-solving strategies;
- deciding when an estimate will suffice vs. an exact answer;
- using tables, graphs, spreadsheets, calculators, and computers to organize, solve, and interpret the results from solving problems;
- judging the validity of the work of others; and
- estimating orders of magnitude to evaluate answers.

To assist you in developing these and other skills in problem solving, below we briefly discuss some ways to solve both open and closed ended problems, and provide references from which you can gain further insight.

Howe's Law: Every person has a scheme which will not work.

The 90/90 Law: The first 10% of the task takes 90% of the time. The remaining 90% takes the remaining 10%.

One of the main objectives of this book is to enhance your **problem-solving** skills. If you can form good habits of problem solving early in your career, you will save considerable time and avoid many frustrations in all aspects of your work, in and out of school. Being able to solve material and energy balances means that in addition to learning basic principles, formulas, laws, and so on, *you must be able to apply them effectively*. Routine substitution of data into an appropriate equation will by no means be adequate to solve any material and energy balances other than the most trivial ones.

In working through this book, develop confidence in your capabilities in problem solving, become aware of your thought processes, get organized, manage

your time effectively, and be flexible in seeking alternative solution strategies. Engineers believe that clearheaded, logical thinking is the way to solve real life problems. Experience demonstrates that such thought processes are not natural, and, in fact, considerable practice must occur before an individual attains the necessary skills. Even for simple problems, the sequence of ideas is usually so tangled up that the interconnections cannot be easily discerned. None of the strategies described here is perfect for you nor necessarily effective for all problems. You have to devise or imitate strategies of solving problems that you feel comfortable with and have demonstrated validity. At the end of this chapter you will find a list of references that offer numerous choices of problem solving strategies. We will mention just a few here.

Polya† recommends the use of four steps for solving problems and puzzles: define, plan, carry out the plan, and look back. The key features of this strategy are the interaction among the steps and the interplay between critical and creative thinking. Fogler and LeBlanc* discuss a five step program: (1) problem definition (problem identification and exploration), (2) generate alternatives, (3) decide on a course of action, (4) carry through, and (5) evaluate the outcome(s). The McMaster five step strategy developed by Woods†† entails a similar set of steps: (1) define, (2) explore, (3) plan, (4) act, and (5) reflect.

The Kepner-Tregve (KT)**pproach to problem solving is also an organized method, the detailed discussion of which can be found in several of the references at the end of this chapter. The KT strategy involves three phases: (1) analysis of the problem, (2) decision procedure, and (3) potential future pitfalls associated with the problem solution. The first two are of interest here.

In the analysis phase, ask questions about the problem such as who, what, where, when, why, and how. For each question also ask what is the situation, what is not the situation, what is the difference between the two situations, and what are possible causes of the difference. For example, for the question "what," ask What is the problem, what is not the problem, what is the distinction between the "is" and "is not," and what cause(s) might arise as these questions are considered. For the question "where," ask what part of the process is affected, what is not affected, what is the distinction, and how do these questions lead to possible causes.

†G. Polya, *How to Solve It*, 2nd ed., Doubleday, New York, 1957.
*H. S. Fogler and S. E. LeBlanc, *Strategies for Creative Problem Solving*, Prentice-Hall, Englewood, N.J., 1994.
††Woods, D. R., *Problem-Based Learning: How to Gain the Most from PBL*, D. R. Woods, McMaster Univ., Hamilton, Ont., 1994.
** Kepner. H. and B. B. Tregoe, *The New Rational Manager*, Princeton Research ress, Princeton, N.J., 1981.

The goal of the decision phase is to select the best solution from the proposed alternatives, and possibly list the priority of alternatives. You can form a matrix (list the goal(s) at the top) in which the heads of the columns designate possible actions to ameliorate the problem or possible choices to meet the stated goal in solving the problem. The rows of the matrix represent, first, the hard constraints, those factors that **must** be satisfied. Next would be listed the group of soft constraints, those that would be nice (but not essential) to satisfy. In each column for each option list the relative rating score (say on a range of 1 to 10) attributed to the degree of satisfaction of a constraint. Addition of the scores in each column helps in reaching a decision. Since many of the weights will be subjective, the final decision is not necessarily based solely on the total of the scores.

As an illustration of the KT approach, examine the following question: What is the maximum number of different rectangles can you build from 12 square tiles using all of the tiles in each rectangle? The options would be various numbers of rectangles: 1, 2, 3, 4, etc. rectangles. The hard constraints would be to (a) use all 12 tiles, (b) make only rectangles, and (c) obtain the maximum number of rectangles. Figure 1 demonstrates a possible matrix to use in solving the problem, and Figure 2 illustrates one way to carry out the analysis (via graphs). You will find considerable merit in going back and forth between visual, verbal, and symbolic representation of a problem.

Constraints	Options (number of rectangles)						
Hard:	1	2	3	4	5	6	7
1. All 12 tiles used	10	10	10	10	10	10	0
2. Only rectangles formed	10	10	10	10	10	10	0
3. Maximum number achieved	0	0	0	0	0	10	0
Soft:							
1. Pleasing shape	0	0	0	0	0	0	0
Total	20	20	20	20	20	30	0

Figure 1 The matrix for problem solving.

Completely novel problems, of course, usually appear to be complex. Figure 3 outlines how your strategy for solving problems is influenced by the information you develop.

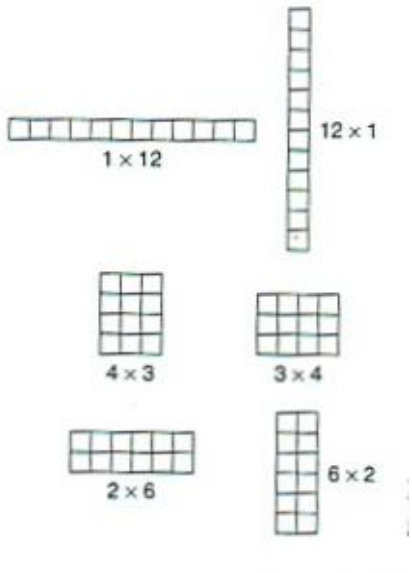


Figure 2 Problem analysis via graphics.

For novel, and particularly for open ended problems, we can for convenience classify the steps in problem solving into five phases (that do not necessarily have to be carried out serially):

1. Understand the problem and the goals
2. Formulate the options for solution
3. Consider the constraints
4. Execute the selected problem solving strategy
5. Evaluate the procedure and results.

In Figures 4, 5, 6, 7, and 8 we have listed for each of the five phases, a set of suggested questions and/or activities to review while engaged in problem solving along with short list of verbs to help stimulate your thought processes.

Start with understanding the problem.

> *It isn't that they can't see the solution. It is that they can't see the problem.* G. K. Chesterton, *The Scandal of Father Brown*.

First, you must identify what results you are to achieve, that is, what the problem is. Then you must define the system, perhaps with the aid of a diagram. Various physical constraints will apply as well as the time

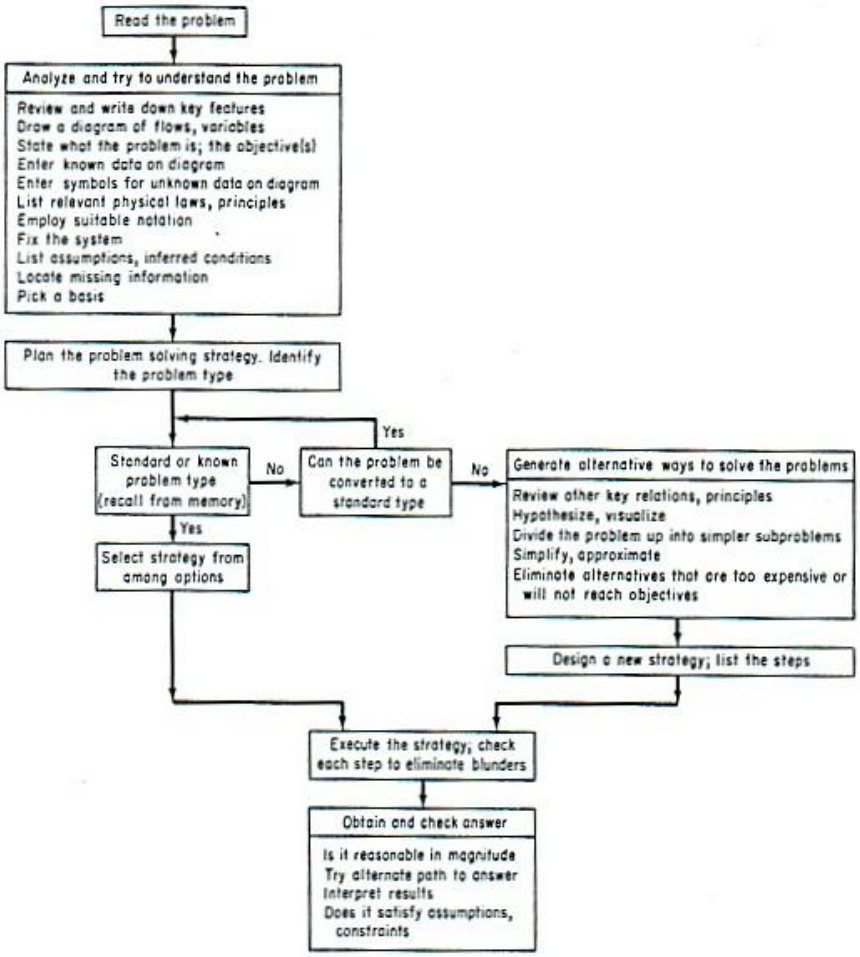


Figure 3 Selection of a problem-solving strategy.

available for you to work on the solution. In almost all cases you will have to look up data and make use of general laws. Finally, the results will have to be presented properly so that you can communicate them to someone else. You can work backward as well as forward in solving problems if the forward sequence of steps to take is not initially clear, and cycle back at will. Problems that are long and involved should be divided into parts and attacked systematically piece by piece.

From the viewpoint of understanding the problem, consider the open ended problem of designing a foolproof way to prevent locking your keys in your car. If you think about this statement, you could, for example, examine options to prevent you from shutting the door with the keys still in the car. However, the problem could be revised to be: If I lock the car with the keys in it, how can I

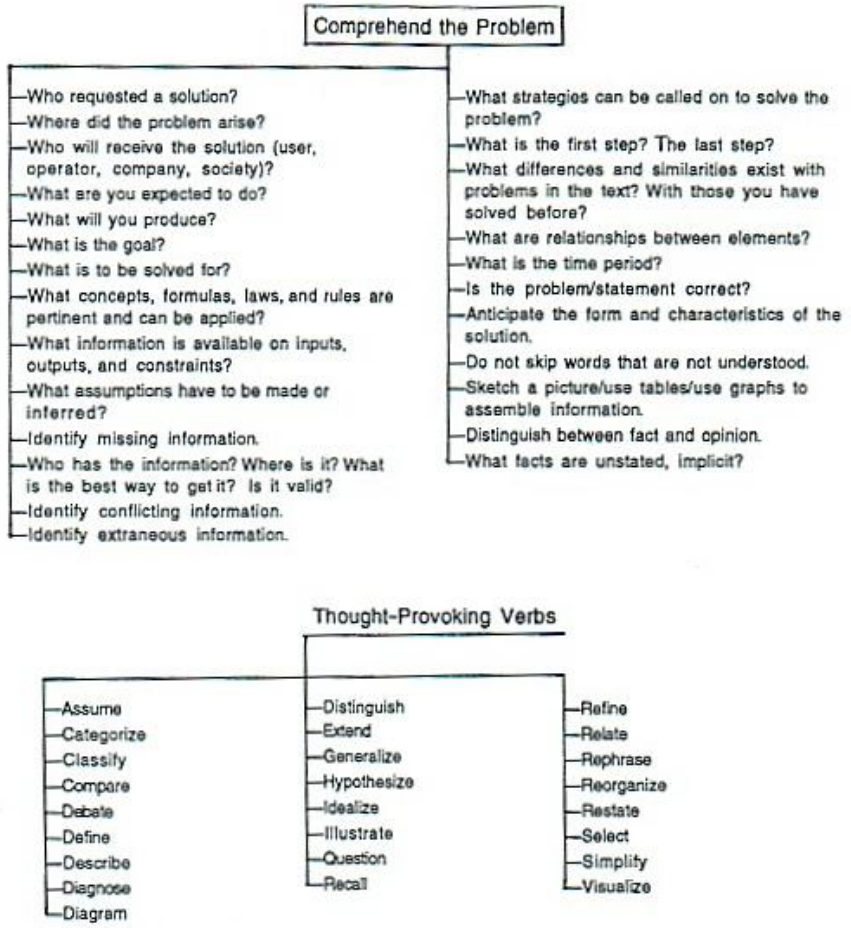


Figure 4 Phase 1: Understand the problem and the goals.

defeat the locking scheme and get into the car? This alternate viewpoint might lead to keeping a duplicate key in your wallet, and so on. By going down the concepts in Fig. 4 and letting your imagination fly free, you can get a sound grasp of what the problem is.

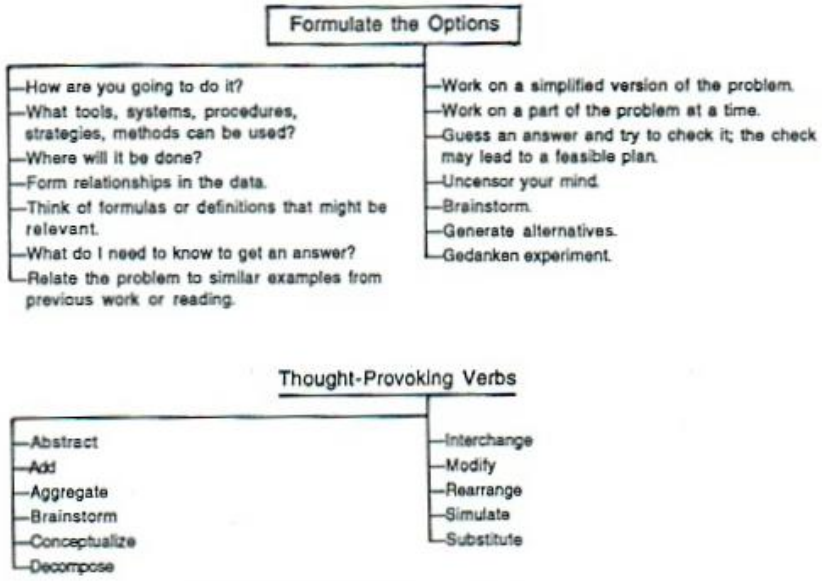


Figure 5 Phase 2: Formulate the options.

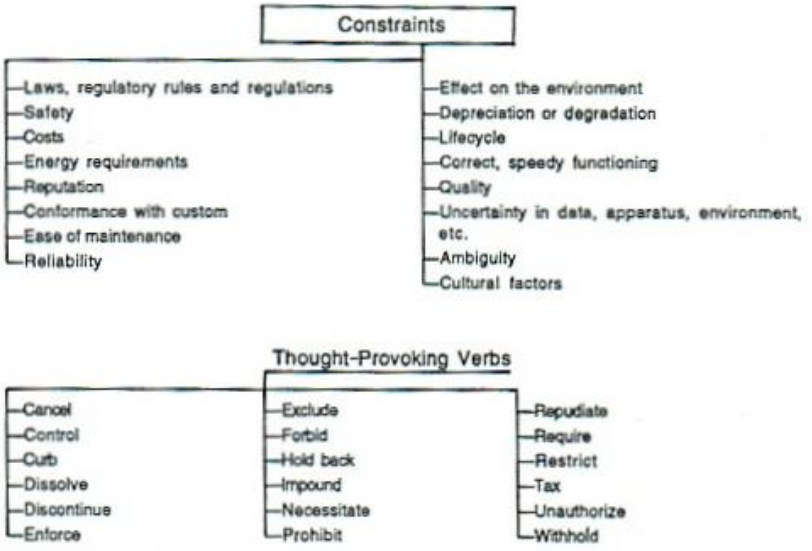


Figure 6 Phase 3: What are the constraints on the options?

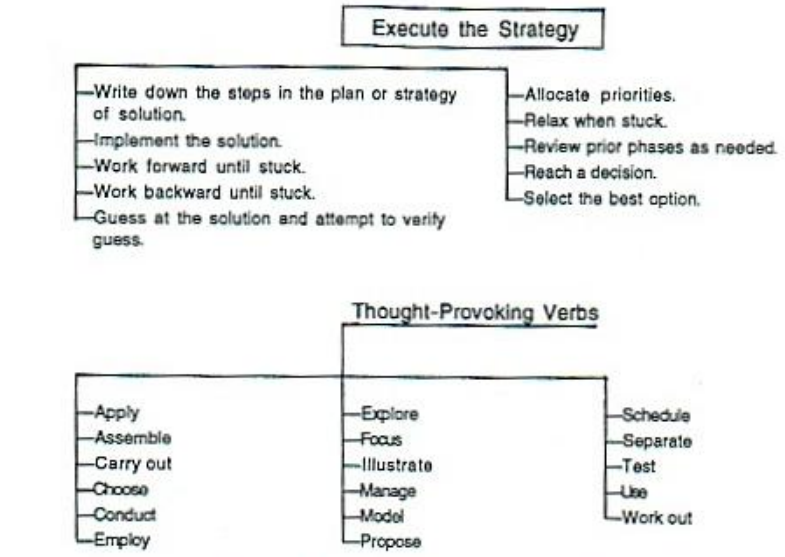


Figure 7 Phase 4: Execute the strategy.

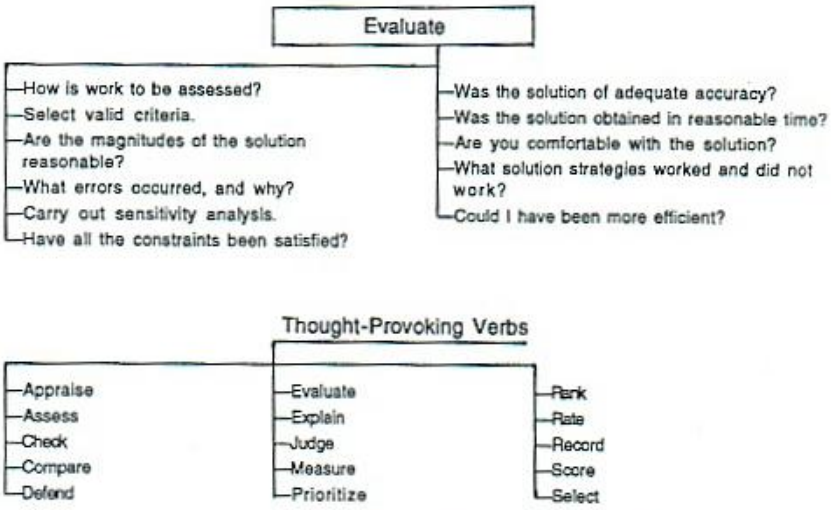


Figure 8 Phase 5: Evaluate the procedure and results.

> *"To have a good idea, you must have a lot of ideas"*--Linas Pauling.

All of us would agree that looking at things from more than one perspective is valuable, outside as well as inside, the profession of engineering. Alex Osborn popularized *brainstorming* and spread creativity training from his advertising agency to business and engineering. Creativity is the process that produces new and valued

responses to problems and at the same time facilitates learning, change, and innovation. Creativity means more than evolving bright ideas. It is more a way of thinking that sheds new light on old problems. It involves developing an ability to think in other than straight lines.

By way of illustrating the development of options, let us return to the problem of avoiding locking your keys in the car. Some options might be

(1) Have an alarm signal if any door opens with the key in the ignition lock,
(2) Require that a car door be positively locked only from the outside with the ignition key,
(3) Eliminate keys and use a key pad instead of a key,

and so on. Application of a little imagination will lead to many more options.

Once you have understood the problem, formulated some options, and ascertained the constraints, you need to select the problem solving procedure and execute it. If the sequence of steps in the procedure is not obvious, take time to set up a plan. If one plan fails, try another.

After reaching a solution to a problem (or failing to reach a solution) you should evaluate what you did. Look at the questions in Figure 8, and determine if your problem solving skills and judgment were satisfactory. Improvement is always possible if you carefully consider what worked and what did not.

What is the difference in the approach to problem solving between an expert and a novice? An expert proceeds in problem solving by abbreviated steps; many are done only mentally. A beginner should go through each step explicitly until he or she becomes experienced. For guidance, perhaps you should turn to Sherlock Holmes (as cited in Arthur Conan Doyle's "The Naval Treaty"):

"Do you see any clue?"

"You have furnished me with seven, but of course I must test them before I can pronounce upon their value."

"You must suspect someone?"

"I suspect myself."

"What?"

"Of coming to conclusions too rapidly."

Table 1 lists activities that an expert may use in problem solving. Table 2 contrasts the problem solving habits of an expert with those of a novice. Table 3 is a checklist for self-assessment of your problem solving traits. How many of the items in the table pertain to your problem-solving techniques? Practice visual thinking, stress management, and awareness of the process whereby you solve

problems. Table 4 is a list of reasons why you may not have been successful in problem solving.

As formulated by Woods,* developing your awareness of your problem-solving skills is an important factor in improving them because

1. You can identify where you are when solving a problem.
2. You can develop a methodical approach.
3. You can, whenever you are stuck, identify the obstacle.
4. You can describe to others what you have done and any difficulties that you are encountering.
5. You become aware of what skills need improvement.
6. You increase your level of confidence.
7. You develop traits of carefulness.

TABLE 1 Techniques Used by Experts to Overcome Barriers to Problem Solving

Read the problem over several times but at different times. Be sure to understand all facets of it. Emphasize the different features each time.

Restate the problem in your own words. List assumptions.

Draw a comprehensive diagram of the process and enter *all* known information on the diagram. Enter symbols for unknown variables and parameters.

Formally write down what you are going to solve for: "I want to calculate . . ."

Choose a basis.

Relate the problem to similar problems you have encountered before, but note any differences.

Plan a strategy for solution; write it down if necessary. Consider different strategies

Write down all the equations and rules that might apply to the problem.

Formally write down everything you know about the problem and what you believe is needed to execute a solution.

Talk to yourself as you proceed to solve the problem.

Ask yourself questions as you go along concerning the data, procedures, equations involved, etc.

Talk to other people about the problem.

D. R. Woods, *Unit 1, Developing Awareness*, the McMaster Problem Solving Program, McMaster University, Hamilton, Ont., Canada, 1985.

Break off problem solving for a few minutes and carry out some other activity.

Break up the solution of the problem into more manageable parts, and start at a familiar stage. Write down the objective for each subproblem (i.e., convert mole fraction to mass fraction, find the pressure in tank 2, etc.).

Repeat the calculations but in a different order.

Work both forward and backward in the solution scheme.

Consider if the results you obtained are reasonable. Check both units and order of magnitude of the calculations. Are the boundary conditions satisfied?

Use alternative paths to verify your solution.

Maintain a positive attitude--you know the problem can be solved--just how is the question.

If you can assimilate the procedures discussed above and make them a part of yourself--so that you do not have to think about the process of problem solving step by step--you will find that you will be able to materially improve your speed, performance, and accuracy in problem solving.

TABLE 2 A Comparison of the Problem-Solving Habits of a Novice and an Expert

A novice:	An expert:
Starts solving a problem before fully understanding what is wanted and/or what a good route for solution will be	Reviews the entire plan outlined in Fig. 2.3, mentally explores alternative strategies, and clearly understands what result is to be obtained
Focuses only on a known problem set that he or she has seen before and tries to match the problem with one in the set	Concentrates on similarities to and differences from known problems; uses generic principles rather than problem matching
Chooses one procedure without exploring alternatives	Examines several procedures serially or in parallel
Emphasizes speed of solution, unaware of blunders	Emphasizes care and accuracy in the solution
Does not follow an organized plan of attack; jumps about, and mixes problem-solving strategies	Goes through the problem-solving process step by step, checking, reevaluating, and recycling from dead ends to another valid path
Is unaware of missing data, concepts, laws	Knows what principles might be involved and where to get missing data
Exhibits bad judgment, makes unsound assumptions	Carefully evaluates the necessary assumptions

Gives up solving the problem because he or she does not know enough	Knows what the difficulty is and is willing to learn more that will provide the information needed
Gives up solving the problem because he or she does not have skills to branch away from a dead-end strategy	Aware that a dead end may exist for a strategy and has planned alternative strategies if a dead end is reached
Unable to make approximations or makes bad ones	Makes appropriate approximations
Cannot conceive of disagreeing	Disagrees with other experts
Slavishly follows instructions; proceeds "by the book"	Breaks rules and makes exceptions
Does not know what to make of qualitative data	Able to deal with qualitative data
Ignores possible limits	Recognizes limits
Fritters times way	Good management of time

TABLE 3 A Checklist of Personal Traits to Avoid in Problem Solving

1. When I fail to solve a problem, I do not examine how I went wrong.
2. When confronted with a complex problem, I do not develop a strategy of finding out exactly what the problem is.
3. When my first efforts to solve a problem fail, I become uneasy about my ability to solve the problem (or I panic!)
4. I am unable to think of effective alternatives to solve a problem.
5. When I become confused about a problem, I do not try to formalize vague ideas or feelings into concrete terms.
6. When confronted with a problem, I tend to do the first thing I can think of to solve it.
7. Often I do not stop and take time to deal with a problem, but just muddle ahead.
8. I do not try to predict the overall result of carrying out a particular course of action.
9. When I try to think of possible techniques of solving a problem, I do not come up with very many alternatives.
10. When faced with a novel problem, I do not have the confidence that I can resolve it.

11. When I work on a problem, I feel that I am grasping or wandering, and not getting a good lead on what to do.

12. I make snap judgments (and regret them later).

13. I do not think of ways to combine different ideas or rules into a whole.

14. Sometimes I get so charged up emotionally that I am unable to deal with my problem.

15. I jump into a problem so fast, I solve the wrong problem.

16. I depend entirely on the worked-out sample problems to serve as models for other problems.

17. I do not plan my time.

18. I am afraid of loosing face.

19. I fail to start on the easy (to me) problems first.

20. I ignore words I do not know.

21. I am easily distracted by the environment in which I work.

22. The stress of problem solving causes blocks and filters out good ideas.

23. Cultural blocks and lack of background information lead me down the wrong path

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SOURCE: Based on the ideas in a questionnaire in P. P. Heppner, *P.S.I.*, Department of Psychology, University of Missouri--Columbia, 1982 plus The University of Texas Learning Aid.

TABLE 4 Diagnosis of Reasons for Failing to Solve Problems
("*Experience is the name everyone gives to their mistakes.*" Oscar Wilde)

Failure to work on a problem in a systematic rather than a scatterbrained way (start too soon; skip essential steps)

Failure to read/understand the problem thoroughly

Failure to draw a diagram and enter all data thereon and the symbols for the unknowns

Failure to ascertain the unknown

Fixing on the first, a poor, or an incorrect strategy of solution without considering alternative strategies

Selection of the wrong principle or equation to use

(total moles instead of total mass, ideal gas instead of real gas) and solution of the wrong problem

Working with false information

Picking the wrong entry from a data base, chart, or table
(wrong sign, wrong units, decimal misplaced, etc.)

Entering incorrect inputs/parameters into calculations
(transpose numbers, wrong units, etc.)

Failure to include units in each step of the calculations

Sloppy execution of calculations introduce errors
(add instead of subtract, invert coefficients, etc.)

Difficulty in distinguishing new features in a problem that superficially looks familiar

Incorrect algebraic manipulations

Use of unsatisfactory computer code for the problem
(too much error, premature termination)

Unable to locate needed data, coefficients by not reading the problem thoroughly or looking in the wrong data base

Unable to estimate what the answer should be to use in comparison with the calculated answer

Knowledge (your data base) is inadequate
(you have forgotten, or never learned, some essential laws, equations, values of coefficients, conversion factors, etc.)

Only forward reasoning rather than both forward and backward reasoning is employed

Emotional stress
(fear of making a mistake, looking foolish or stupid)

Lack of motivation

Inability to relax

Looking Back

In this section we briefly described several problem solving strategies for novel and open ended problems.

Key Ideas

1. Many problem solving strategies have been proposed--you have to find one that meshes with your background and viewpoint.

2. All effective problem solving strategies involve the phases of determining what the real problem is, generating alternative solutions, developing a precedence order for the solution, executing the solution, and evaluating the outcome.

Self-Assessment Test

1. Prepare an information flow diagram showing the sequence (serial and parallel) of steps to be used in effective problem solving.

2. Take an example from one of the Chapters, and program the thought process needed to solve the example problem. Show how the following classes of information are connected (put the solution as the last stage of the tree at the bottom):

(a) Information stated in the problem
(b) Information implied or inferred from the problem statement
(c) Information from your memory (internal data bank!)
(d) Information from an external data bank (reference source)
(e) Information determined by reasoning or calculations

Label each class with a different-type box (circle, square, diamond, etc.) and let arrows connect the boxes to show the sequence of information flow for your procedure.

3. What should you do if you experience the following difficulties in solving problems?
(a) No interest in the material and no clear reason to remember
(b) Cannot understand after reading the material
(c) Read to learn "later"
(d) Rapidly forget what you have read
(e) Form of study is inappropriate

4. Apply the K-T method to solve the following problem.

> A man has a raft and three cantaloupes. Each cantaloupe weighs a pound. However, the raft can hold only 202 pounds, and the man weighs 200 pounds himself. How does the man get to the other side of the river with the cantaloupes? (His weight includes his clothes and the cantaloupes can't be thrown across the river.)

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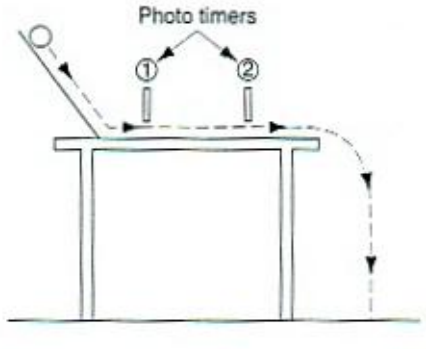
Problems

2.1. I have always checked the condition of my battery by checking the specific gravity with a hydrometer. I recently purchased an Exide battery. The specific gravity of the battery stays about 1.225 whether the battery is fully charged or completely discharged. How is this possible?

2.2. Which is the greater amount, 1 dozen eggs, 6 watermelons, or 3 bars of gold?

2.3. What do Catherine the Great, Attila the Hun, and Eric the Red have in common?

2.4. Two problems that are posed alike can really be quite different, for example:
1. It takes 1 man 5 days to dig a ditch. How long does it take 5 men to dig the ditch?
ocean. How long does it take 5 ships to cross the



exactly alike: Just substitute *ship* for *man* and then do the answers differ?

ape of dog pen should you construct for your dog?

the time it takes for a ball to roll across the tables.

eter stick used to measure the height of the table is
the location on the floor where ball hits be
e instruments and ruler?

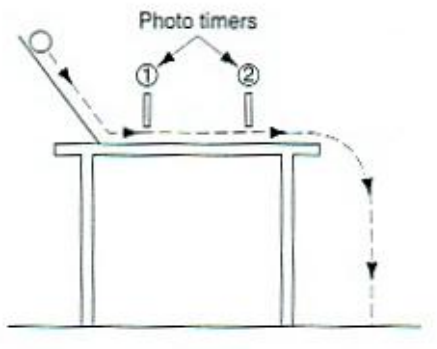


Figure 2.6

2.7. One day in Chicago when the air temperature was in the high 90s, a truck containing morpholine was in an accident and sprang a leak. The fire chief of the Chicago suburb involved appeared on the 10:00 o'clock news and explained that the air temperature that day was almost 100°F, and that 100°F is the flash point of morpholine. He then went on to explain that when the flash point of morpholine is reached, the morpholoine will explode. He further said that it was very irresponsible for materials with such low flash points to be shipped on a hot day.

Is the chief correct?

2.8. **The Russian Vase**

Bursting through the double doors of the hotel kitchen, Kim Matthews leveled her gun at Philip Jacobs. Whipping away from the industrial stovetop to face Kim, Philip's apparent panic faded into a sinister smile.

"You'd like to arrest me, wouldn't you?" Philip looked around at his surroundings and then back at Kim. "But, whatever for?"

"For . . ." Kim began, but was interrupted by Detective Barry Stone, coming through doors behind Kim, "If he doesn't have the vase, you can't arrest him."

"That's right," Jacobs said, sauntering past Kim and out of the kitchen.

"I just don't get it, Barry," Kim said, "I saw him steal the crystal vase out of the Russian ambassador's exhibit in the lobby, and then I chased him in here. The vase wasn't that large, but it couldn't have been hidden that easily, that fast," Kim said, motioning to the kitchen which was cluttered with the typical pots and utensils used in the hotel food industry. A butcher's block covered with fresh vegetables spanned the length of the right wall, blending into the stove top range with its large double doored oven, seared grills top, and a large bucket of cooking oil at the foot of the oven doors. Numerous deep sinks and counters used for washing dishes covered the left side of the kitchen, and in the middle stood the typical island cluttered with various knifes and other utensils.

"Who is this Jacobs, anyway?" Kim asked Detective Stone.

"Strangely enough, he's some optics professor from a local university who just cracked one day. Anyhow, I'll have my men search his place from top to bottom, in the mean time why don't you keep an eye on Jacobs."

"Actually, Barry, I think you'll have to do that. I'll go and arrest Jacobs, this time for real."

"Why did Kim Matthews decide to arrest Jacobs?

2.9. The Laboratory Fire

Kim Matthews waded through the sea of firefighters and policemen to reach Detective Barry Stone who was standing in cleared alcove next to the main counter in what remained of a chemistry laboratory.

"Kim, I'm glad you could come," Detective Stone said gesturing to the condition of the laboratory. "Obviously there has been very high temperature fire that melted steel and crumbled the concrete. >From what the fireman can tell me, it seems to have been caused by a gas leak in the gas line to the hood. The gas line looks as though it got run into by a cart too many times, and due to the age of the line, it most likely just cracked easily. Anything could've caused the spark. During the fire, orange smoke billowed out of the lab, and it was impossible to put the fire out by way of the sprinkler system.

"Whose lab is this?" Kim asked.

"It used to belong to a Professor Bob Koker, and from the reaction of some passing students, he wasn't too popular. Here he comes now."

"All my work, gone," Koker began. "I can't believe my life's work has been destroyed by an insignificant gas leak," Koker exclaimed. "Now I will have to spend more of my time teaching those sniveling students!" Turning on his heel, Professor Koker took off towards the door of the lab.

"In how own world, I guess. Poor guy," Stone said while reaching for his notepad on the counter. "Ugh!, what is this?" Stone exclaimed noting the white powdery dust that was picked up on his notebook from the white dust covering the lab bench.

Turning, Kim scanned the floor by the bench which she now observed was covered with the white powder.

With a sinister gleam in her eye, Kim said, "This explosion wasn't an accident Stone, of that I'm sure. Let me have the dust analyzed" (The dusk proved to be a mixture of aluminum oxide and ammonium nitrate).

Later that week Matthews told Barry to start interrogating Koker's students. What made Matthews so sure that the explosion was not an accident?

2.10. Why does popcorn pop? Review the possibilities and carry out experimental observations to test hypotheses.

2.11. How can leaks from a gas pipeline be detected in practice?

2.12. One effect of potential global warming is the acceleration of the decomposition of organic material

Answers to the Self assessment Test

1. A serial sequence is adequate; some steps can be in parallel. Feedback may be inserted at various stages.
3. **(a)** Find a reason to remember; talk to others who are interested to ascertain what motivated them. Write down the reason for periodic pep talks with yourself.
   (b) Get a "bird's-eye view" of the whole section. Use the figure numbered 0 to see the relation to other sections. Look at a similar textbook. Ask for help; do not wait.
   (c) After scanning the serious reading count.
   (d) Take a few minutes as you read to mentally test yourself on what you have just read to reinforce learning. Continue to test at periodic intervals.
   (e) Practice using the information for an assumed quiz; predict quiz questions; use text examples or problems as samples.
4. Some possible options are: (1) obtain a rope or a net or a piece of clothing, and tow the cantaloupes across; (2) juggle the cantaloupes keeping one in the air—violates the laws of physics; (3) throw the cantaloupes across—even if they get to the other side, they will be smashed; (4) get a better raft; and many other possibilities.

Answers to the Problems

2.1	It's possible with a broken hydrometer. It's time to buy a new one.
2.2	It depends on what the problem is. Does "greater" refer to volume, number, mass, value, or?
2.3	The same middle name (the)
2.4	They differ because additional information (engineering knowledge) is required to relate the mathematical statement to the actual application. You can say that the units associated with the numbers make the difference in the real world. While 2 kg of water + 2 kg alcohol = 4 kg solution, 2 cm^3 of water + 2 cm^3 of alcohol $\neq$ 4 cm^3 of mixture.
2.5	Possible options are largest area pen, longest pen (to permit running), closest to house that will form one side, etc.
2.6	Apply the propagation of error relation to the dynamic equations from physics. Or, consider a combinatorial set of cases for deviations of measurements (high and low from accurate), and predict the deviation in landing for each case. Interaction (multiple errors) have to be included in the analysis.
2.7	Morpholine has an autoignition temperature of 590°F (apparently what the fire chief was thinking of). In Hawley's Chemical Dictionary, morpholine is listed as a moderate fire risk.
2.8	Jacobs is a optics professor. Kim caught him in front of the stove next to the bucket of oil. Remembering her physics, Kim figured out that crystal has the same index of refraction as cooking oil. Therefore, when Jacobs dropped the vase in the oil, it because invisible. The options to choose from by the K-T method were all of the individuals involved in the case description. The constraints were motive, timing, opportunity, knowledge, observed (reported) taking the vase, size of the vase, admission of guild.
2.9	What Kim noticed was the Al_2O_3 covering the lab surfaces. Al reacts with NH_4NO_3 to produce Al_2O_3, H_2O, and N_2 so that the only product remaining from the fire would be a powder. After easily breadking open one of the old gas lines near the hood, the culprit left the bomb on the main counter. The bomb ignited the escaping natural gas and BOOM! Due to Detective Stone's comment about the students' opinion of the professor and the attitude of the professor himself, Kim suspects it was a student who planned the bomb.

2.10 An explanation of the process (our hypothesis) is

1. As temperature rises, water inside the kernel becomes steam
2. Trapped steam exerts an increasing pressure on the hull
3. The hull tears at its weakest point
4. Escaping steam expands out the hole
   a. pushing the contents out and fluffing them
   b. inverting the hull
   c. pushing the kernel in the opposite direction.

Possible tests of this model are:

1. Is the condensate water?
2. Does the mass of a kernel decrease after popping?
3. Is the mass of the water lost (recover by trapping) equal to the mass lost by the kernel? (Briefly discuss the conservation of mass). How does the odor detected fit into this?
4. Does drilling a hole in the kernel prevent popping? Are the kernels which did not pop cracked or broken?
5. Will kernels pop at less than 100°C?
6. Will they pop in a pressure cooker? (Discuss how a pressure cooker works, and note that water is added to produce the steam).
7. Can the popping process be captured by high-speed photography?
8. Can we cut a kernel in half and see the structure?

Other questions:

(1) Is the necessary air stored inside the kernel? The high density implies little free air is present, and the known long lives of seeds (months to decades) render it unlikely that enough could be present. The required air probably comes from the atmosphere.

(2) Is there a one-way trap door that allows gases in but not out? Since the net reaction involved is

$$\text{starch} + O_2(g) \rightarrow H_2O(1) + CO_2(g)$$

this implies a buildup of CO_2 inside the kernel and eventual popping without heat.

(3) Is there a hole small enough to let oxygen in but not steam out? An oxygen molecule is nearly twice the size of a water molecule.

(4) Does heating cause the hole(s) present in the kernel to swell shut, allowing steam pressure to build up?

(5) Is there a small hole that allows oxygen to enter slowly but cannot vent the rapid steam build-up?

2.11 Some methods might be (1) acoustic emissions (created by cracks) -- nondestructive, sensitive, passive, but must interpret signatures; weak signal, inconsistent; (2) portable flame ionization detectors (cheap, portable, but must move to site, requires manpower; (3) examine fluid turbidity; and many more options.

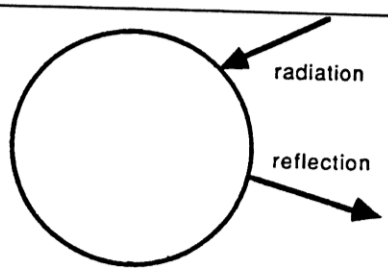
2.12 For a brief but thorough explanation refer to *Nature*, Vol. 351, 1991, p. 304.

2.13 Only one material flowing, steam. The answers for the base case are:

$x_3 = 20.684$	$x_{10} = 0$
$x_4 = 2.906$	$x_{11} = 11.562$
$x_5 = 20.339$	$x_{12} = 27.957$
$x_6 = 24.200$	$x_{13} = 8.045$
$x_7 = 95.801$	$x_{14} = 290.556$
$x_8 = 2.421$	$x_{15} = 0$
$x_9 = 14.619$	$x_{16} = 164.70$

2.15
a. $x_1 = 1, x_2 = 3, x_3 = -3$
b. $x_1 = x_2 = x_3 = 0$
c. $x_1 = 1, x_2 = 3, x_3 = 1$
d. multiple solutions exist

2.16.



Need an energy balance that accounts for radiation from sun, and reflection to space. The independent variable would be temperature and the dependent variable would be time. Need to relate the reception and loss of energy to temperatures that are known, or rates of energy transfer that are known, from the sun and to outer space.

2.17
1. 3.82 g/cm^3
2. 305 – 309°C
3. 8 g/100 g H_2O
4. 24.00 ft^3/lb

2.18 Yes; Yes; Yes.

2.19 Examples:
(1) J. of Chemical and Engineering Data
(2) Chemical Reviews
(3) J. Chem. Physics
(4) J. Inst. Stds. Technol.