ChE classroom

USING TROUBLE SHOOTING PROBLEMS*

Edited by
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Professional engineers must be good at solving a variety of problems. A type of problem that professionals encounter often is the trouble shooting or diagnostic problem. In such problems, an unexpected difficulty has arisen; something is wrong that must be corrected immediately, safely, and with a minimum of cost. Here is an example: "For the past 10 minutes the product has been off-specification; get this corrected because we are losing $2000 for every hour we produce this unsaleable product!" The problem can be caused by technical mistakes, people mistakes, or misunderstandings. The data required to solve the problem usually have to be collected. This type of problem can provide a very effective vehicle for motivating students and improving their skill at solving problems. It can be used to train undergraduates, graduates, and professionals in industry. Some examples of how these trouble shooting problems can be used have been given previously [1, 2, 3, 4]. The purpose of this article is to extend the ideas presented in those early articles and to illustrate the variety of approaches that can be used.

TROUBLE-SHOOTING AT CANADIAN INDUSTRIES LIMITED

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The following comments describe not how trouble-shooting cases are used as a training aid, but how trouble-shooting in general fits into an industrial environment and how an engineer can take advantage of the problem solving opportunities facing him. Some ground rules are then offered that hopefully will aid readers in avoiding some of the common pitfalls of problem solving. The comments pertain to a heavy industrial site consisting of several chemical plants of different types.

The trouble-shooting technique has been described elsewhere and we will not go into detail here. Basically, it can be described as the use of the scientific method and sound engineering principles to solve problems. The four basic steps in the problem solving process are:

1. **Realize something is wrong.**
2. **Define the problem; collect data.**
3. **Make conclusions; evaluate possible solutions.**
4. **Implement the solution.**

TYPES OF PROBLEMS ENCOUNTERED

In heavy industry, problems can arise at several levels of sophistication ranging from simple mechanical failures to innovative debottlenecking studies. The same trouble-shooting techniques can be used over this whole range of problem solving activities.

At the basic level, problems will be encountered with operating plants and Step #1 in the above-mentioned method will be quite easy: the product is off-spec., a pump does not work, production rate or efficiency is below normal, etc. You do not need anyone to tell you something is wrong; it is quite obvious. The fault, however, may not be so easy to find. It may be easy to determine what is wrong with a pump, but, diagnosing that a heat exchanger has an internal leak might be considerably more difficult. These trouble-shooting problems are

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generally handled by plant operating personnel but in some cases they may need help. The engineer, whatever his responsibilities, should make an effort to get involved in these problems. He will gain valuable experience in dealing with practical problems, and even if he is not directly involved he should assure himself that the proper trouble-shooting procedures are being followed. Because Step #1 is "given", this is also the type of problem that can be used in the case study/classroom method of instruction.

At the next level of sophistication the term trouble-shooting gives way to the more general term problem solving. Also, Step #1, the realization that something is wrong, is by no means obvious.

At this level, looking for and finding problems is the key and the engineer should play a dominant role. Plant operating personnel are generally very familiar with their equipment, its operating characteristics and limitations. They will operate their equipment to the best of their and the equipment's ability. They will come up with ideas to improve things, but they are not plant designers and may not recognize design errors. An example of this type of problem is a high pressure drop in piping system that limits the output of a pump or compressor. As far as the plant operator is concerned, it is not a problem as long as it works. The engineer, however, should be able to recognize this as a problem (Step #1) and then collect data, check the calculations, design data, etc., before reaching a conclusion. This type of problem will command attention when production is limited (the squeaky wheel gets the grease syndrome) but otherwise just how many similar problems are waiting to be discovered? Another type of example in this category is that of equipment and instrumentation systems that are too complicated to do a simple job; the result can be poor operations and a lot of effort expended to make something work when the real solution is to simplify the installation and eliminate unnecessary equipment (provided, of course, that safety and reliability standards are maintained). Clearly the ability to recognize, as well as solve, problems is a key asset for any engineer. The techniques for finding problems are similar to those used for solving them. By asking the right questions (of himself, the plant designers, the plant operators, etc.) and by remaining somewhat of a skeptic the engineer is sure to uncover problem areas. In the development of a new engineer, the ability to recognize problems can often be a key turning point.

We are now overlapping into the next level of problem solving; that is optimization, de-bottlenecking and even innovation. The same techniques apply as for basic trouble-shooting. At this level the problem definition (Step # 2) and evaluation of alternatives (Step # 3) will require substantial engineering input. In the past few years, as energy costs have soared, opportunities have arisen to make existing plants more efficient. In a general sense this can be considered a problem solving activity. Many of the solutions to optimization, de-bottlenecking, and energy-related problems are considered innovative but they are really just the result of a lot of hard work and are a logical extension of the application of trouble-shooting techniques.

To summarize, demonstrated problem solving

The engineer, whatever his responsibilities, should make an effort to get involved in these problems. He will gain valuable experience in dealing with practical problems, and even if he is not directly involved he should assure himself that the proper trouble-shooting procedures are being followed.

A major source of trouble-shooting problems should be our industrial colleagues. This is true especially now, when many, if not most, faculty members have had little or no industrial experience.

ability is a valuable asset for any engineer. The ability to recognize and solve problems is the key to a successful career for many engineers and the engineer who is good at solving problems is also likely to be considered an innovative engineer.

GROUNDRULES FOR TROUBLE-SHOOTING

The following is offered as a partial list of guidelines in order to avoid some of the common pitfalls of trouble-shooting.

1. It goes without saying that there is no substitute for a knowledge of fundamentals, whether it be fluid flow, process control, distillation theory, etc.
2. Similarly, there is no substitute for knowledge of the process/plant/equipment/etc. having the problem.
3. When defining a problem (Step #2), do not confuse someone's interpretation of what is wrong with the observations. Human nature being what it is, people will tend to give their theories or conclusions as to what is wrong, instead of reporting observations. Perhaps they are right but their conclusions may not be supported by the facts. A common mistake is to jump to a conclusion that a particular thing is at fault because this is a common type of failure. Many, or most, people are guilty of these tendencies, including engineers.
4. While working on a problem an engineer may want to collect plant data, conduct test runs, have samples analyzed, etc. It is important that the engineer collect the data himself, be present when the data is collected, or otherwise assure himself that the job is being done properly.

Many needless hours have been wasted on poor data resulting from uncalibrated plant instruments, mislabelled sample bottles, missed readings, etc.

When relying on non-routine lab tests the engineer should have an understanding of the analytical techniques used and whether or not they will tell him what he wants to know. Accuracy and reproducibility of the tests should be known. If the lab technique is dependent on the use of known standards then the number, age, condition and range of the standards should be known. If you are analyzing for 2% component x and the only standard contains 50% component x then all the results may be meaningless. It has also been known for standards to be wrong and using two or three standards can eliminate this possibility.

5. Be aware of any assumptions you make when solving problems. Be prepared to re-examine assumptions and to discard them when necessary.

TROUBLE-SHOOTING AT THE UNIVERSITY OF WISCONSIN

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We have used a few trouble-shooting problems; however our main emphasis has been on the more structured and synthesis type of problem, in the form of developing a reasonably near optimum design to fit a given need. From our experience here are some thoughts about the advantages and disadvantages of using trouble shooting problems.

Advantages

1. Student introduction to the type of situation he (or she) will meet in pilot plant operation, production, sales and service, etc. (most students confess they have no idea how what they are learning will translate into professional life. Only a few of our students will graduate with adequate industrial summer work experience, to judge from recent observations.)
2. Experience gained in the sort of practical reasoning which is important in industrial work. Standard theory courses can afford neither the time for this nor the distraction from the orderly development of theoretical principles which such problems would entail.
3. Showing the student, by actual demonstration, that there may be more than one way to reason through a problem.

Disadvantages and precautions

1. Some trouble-shooting problems are such that it is not reasonable to expect inexperienced

people to reason from effect to cause. There may even be more than one chain of events which would lead to the observed effect, or effects, so the cause cannot really be determined. Even an experienced engineer can be misled.

2. Supposing that we devise problems with an unique and correct result from such backward reasoning, there is danger in tempting the unwary student to generalize, and to believe this will always be the case with real life problems. The keen student is going to be suspicious of what seems to him (or her) a cooked-up problem, and will wonder if such exercises really lead to practical proficiency.

The above difficulties can, of course, be handled by careful presentation and adequate discussion and summing-up by the instructor; they can be made to contribute to the practical instruction of the students, particularly if they are given an adequate role in these discussions and allowed a measure of discovery of the character of trouble-shooting problems. But the problems used have to be either real ones, or very carefully thought-through synthetic ones.

A major source of trouble-shooting problems should be our industrial colleagues. This is true especially now, when many, if not most, faculty members have had little or no industrial experience. Of course, good consulting experience can provide problems, too.

Trouble-shooting may well be approached more efficiently by applying some rational analysis, when time permits. One may thus be more successful, especially when there is a complex chain of consequences from an original fault in a system, with secondary faults, etc. Applications of fault-free analysis, as is done in raliability studies, might even be programmed for computer solution so that a large number of failure patterns can be examined. Observations which indicate potential trouble, or which follow actual system failure, could then be matched to the analyses and the probable cause inferred. Dale Rudd and his students have done fruitful work in this area [6, 7]. Long ago, we concluded that there was a structure to disaster, which behooves the engineer to study carefully.

We are now overlapping into the next level of problem solving; that is optimization, de-bottlenecking and even innovation.

TROUBLE SHOOTING CASES AT McMASTER HEALTH SCIENCES

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In the Faculty of Health Sciences, we have centred our educational program around the biomedical or health care problem. Our conviction is that the students learn best when *they* choose what they need to learn. The problem is in the vehicle for learning. These problems are encountered in the regular work of a Medical Doctor, and so it is natural that our emphasis is on this type of problem. Primarily we use one format: small groups of five students together with a tutor identify the issues in any problem, discover what they need to know, learn that information through self study, determine the underlying mechanisms and propose short and long term corrective actions. The structure of these problems is modelled on extensive research done on the diagnostic process in medicine.

The problems . . . provide opportunities for the students to learn the necessary background knowledge to function successfully as an M.D.

The distinctive characteristics of our approach are:

1. Students obtain information on their own and share it with other student members in the group,
2. The tutor's role is supportive and aimed at developing productive group and problem solving skills,
3. The students prepare their own objectives and questions they wish to explore, within the general framework for a particular 10-week unit,
4. The student is guided through the stages of cues-hypothesis-inquiry strategy and decisions as well as through the self directed studies.

The problems are carefully selected to provide opportunities for the students to learn the necessary background knowledge to function successfully as an M.D.

What format is used for the problem statement? We use at least two major formats (the box problem, and the paper case protocol) with enrichment available through simulated patients, and the P4 card deck computer simulations. The problem box provides the student with the initial problem statement, and a self-paced set of key questions relating to the topics to explore. The box may include pertinent slides, audio tape of an M.D. interviewing the patient, X-rays and laboratory test result sheets. This additional information will be needed as the students work through the problem. In the simulated patient format, a well-trained, healthy patient portrays an actual patient with a given illness and can thus respond to the students with appropriate answers and systems.

In the computer simulation format, various systems of the body are simulated on the digital computer. Faults with the system are programmed in and the student is expected to discover the faults by asking the right questions and interpreting the output data. This approach is similar to that used by Doig [5]; however, here we are dealing with a simulation of a medical system.

In the P4 card format, the student is given a deck of cards, based on an actual patient problem, from which he selects the card most likely to him to identify the fault and prescribe a cure. An initial card poses the problem. He may select from about 50 "questions I must ask the patient". Each card asks the student to state to himself where this question (or card) fits into the problem definition, the hypotheses he is developing, and the information he needs. On the back of each card is the answer to the question. Another possible set of cards provides the answers to examination tests the students might wish to do. This set provides about 25 alternatives.

The student may choose from about 30 laboratory tests he might want done or he may choose to bring in one of 20 different expert consultants. From the student's selection of cards from these four sources of information he should be able to identify the fault. He then chooses one of our forty medications or patient care prescriptions. The exercise is completed by means of a closure card. Experienced diagnosticians have made their choice of cards and the "good" choices are coded so that the student receives instant feedback as to the quality of his choice: +2 if his choice coincides with that of the expert and -2 if he makes a poor choice. A problem box and P4 deck have been developed for this type of problem. The Problem Box consists of charts, photograph, x-rays, and written data. The P4 deck consists of five different sets of cards from which the problem solver can select those that he/she feels are pertinent. More details of the complete program are described elsewhere [8, 9, 10].

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TROUBLE SHOOTING AT McMASTER

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At McMaster three different formats have been used:

1. Students work on their own to determine the cause, and pose short and long term corrective action.
2. Students work as a group to determine the cause, and pose short and long term corrective action.
3. Students work on own to outline cause finding strategy.

The first two formats are similar and will be the main emphasis described here. The third format is used on examinations and is similar to that used at the University of Waterloo [3, 4].

The distinctive characteristics of our approach are:

1. Students obtain information from the instructor by asking questions about past experience, results of calculations, and results of experiments that the student wants performed.
2. Students do not do any calculations.
3. Students are charged a cost related to the downtime and direct costs incurred because of their questions.
4. The "best" solution is that where the problem is solved with the minimum total cost.
5. Students are not limited in the types of questions they can ask.

With the individual format the students write down the question they want answered or experiment they want performed, raise their hand and

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receive a written answer immediately from the instructor. With the group format, the students choose a chairman whose role is to focus discussion on what question they want answered and forward the question through to the instructor for his response. About one tutor or instructor is required in the room for every ten students.

What problems do we use? We have an initial set of about 15 that we developed from our industrial experience. Now our former students send us sufficient industrial problems each year to supply new situations and challenges for subsequent classes. A set of such problems is available. We are currently exploring the appropriateness of running these sessions at the plant in a local industry, using problems they encountered and interacting with plant personnel.

The advantages of this approach are that the students begin to appreciate the cost implications of their decisions, and they can ask any question they like. There are two extreme approaches to solving these problems: the Kepner Tregoe approach (where the focus is on discovering when in time some change was made to cause the fault [11, 12, 13] and the hypothesis generation approach where all the current evidence is analyzed, alternative causes are created and most likely alternatives are tested. This format allows the student to use either method or a combination of these methods to solve the problem.

The main difficulties the students have are that they cannot accurately estimate the time required (and hence the cost) to answer some of their questions, they usually are not very organized in their approach to solving this type of problem, and they rely almost entirely on the hypothesis generation approach. To overcome some of these difficulties we have listed time and cost estimates for many commonly performed analyses, experiments or equipment modifications. To try to discover how to improve their approach to solve problems we have started a separate project. Details of this approach are available elsewhere [14, 15]. □

REFERENCES

1. Woods, D. R. (1966). "Complement to Design: Trouble-Shooting Problems." Chem. Eng. Education. Jan. p. 19-23.
   Woods, D. R. (1968). "Trouble-Shooting Problems: Problem Specifications" and (1973) Teacher's Guide. McMaster University, Hamilton.
2. Woods, D. R. (1967). "The Use of Short Trouble Shooting Problems." Chapt. 3 in "Chemical Engineering Case Problems," C. J. King, editor. AIChE. New York.
3. Silveston, P. L. (1967). "Trouble Shooting Problems as Teaching Aids." Chapt. 4 in "Chemical Engineering Case Problems," C. J. King, editor. AIChE, New York.
4. Silveston, P. L. and Woods, D. R. (1966). "Use of Trouble-Shooting Problems in Undergraduate Chemical Engineering Design Courses." Paper presented at the CSChE Conference, Windsor, Ont. Oct. 19.
5. Doig, I. D. (1977). "Training of Process Plant Malfunction Analysts." Chemeca 77, Canberra, 14-16 Sept. p. 144-148.
6. Rivas, J. B., Rudd, D. F. and Kelly, L. R. (1974). "Computer-aided Safety Interlock Systems," AIChE Journal *20*, No. 2, p. 311.
7. Rivas, J. R. and Rudd, D. F. (1974). "Synthesis of Failure-Safe Operations." AIChE Journal *20*, No. 2, p. 320.
8. Barrows, H. S. and Tamblyn, R. (1977). "Guide to the Development of Skills in Problem Based Learning and Clinical (diagnostic) Reasoning." 53 p. Monograph NA.1., McMaster University, Faculty of Health Sciences, Hamilton.
9. Barrows, H. S. and Bennett, K. S. (1972). "The Diagnostic (Problem Solving) Skill of the Neurologist." Archives of Neurology *26*, p. 273-277. March.
10. Neufeld, V. R. and Barrows, H. S. (1974). "The 'McMaster Philosophy': An Approach to Medical Education." J. Medical Education *49*, p. 1040-1050.
11. Kepner, C. H. and Tregoe, B. B. (1965). "The Rational Manager." McGraw-Hill.
12. Kepner, C. H. and Tregoe, B. B. (1973). "Genco II." Kepner-Tregoe Inc., Princeton, N.J.
13. Kepner, C. H. and Tregoe, B. B. (1973). "Problem Analysis and Decision Making." Kepner-Tregoe Inc.,
14. Woods, D. R., Crowe, C. M., Hoffman, T. W. and Wright, J. D. (1977). "What is the Problem in Teaching Problem Solving?" To appear in the ASEE monograph on Problem Solving.
15. Woods, D. R., Crowe, C. M., Hoffman, T. W. and Wright, J. D., (1978). "56 Challenges to Teaching Problem Solving." McMaster University, Hamilton.

ChE book reviews

CHEMICAL AND ENGINEERING THERMODYNAMICS

By Stanley I. Sandler
John Wiley & Sons, N.Y.
Reviewed by C. M. Thatcher
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Prof. Sandler sets forth two specific objectives in the preface to his book. The first is to provide a modern textbook, particularly relevant to other courses in the curriculum, for an undergraduate course in chemical engineering thermodynamics. The first part of this objective, at least, has been