World Transactions on Engineering and Technology Education
Vol.3, No.2, 2004

Educating: problem-solving

Ron B. Ward

University of New South Wales
Sydney, Australia

ABSTRACT: Much of an engineer's work involves solving problems of one sort or another. Young engineers meet this early in their career, for example, in design work. Actually, that hits them while still a student, because all engineering students do some type of design subject, which contains assignments that are, essentially, problems-to-be-solved and, in those subjects, students are given procedures, processes and protocols by which the problem may be solved. But those procedures are specific to the subject and, indeed, are often specific to the particular problem; hence, they are not generally applicable. So how does the graduate engineer who has moved into the work environment solve his/her work related problems? It is surmised that it is by developing an internal mental system based on previous experience (which may be relatively short). Pondering this has led the author to question: why are engineering students not given some generic instruction on how to solve problems? There is sufficient knowledge on problem-solving, of a general nature, to provide such instruction, and the paper based on this abstract will outline what should be taught so that engineering students are given generic procedures for solving problems.

INTRODUCTION

The author begins an investigation into problem-solving methods by determining generic procedures for solving problems, beginning with some introductory thinking.

Where does problem-solving begin? It begins with a task related to it, problem-finding, which usually *just happens*, particularly for engineers, in that problems seem to find us, rather than the opposite.

Why is problem-finding and problem-solving important? This combination, problem-solving-and-finding, is important because they can be the step that leads to decision-making. The reason for putting this in such a way: *the step that leads to decision-making*, is that one cannot make a decision until one knows what requires a decision, and what the alternative decision-choices are – all that is just another way of stating that solving a problem leads to making a decision.

That may sound complicated, so think it through this way: without a problem and alternative solutions, there is no need for a decision. Both problem and alternatives are necessary as a lead-up to a decision. Then, if a problem exists and a solution is demanded, and there is only one answer, no decision is needed – or possible. The only feasible decision seems to be: use that one answer.

Well, that is not *quite* correct, because even in the case of having only one solution-answer, there is an alternative, which is to do nothing, and choosing that is, of course, making a decision. In some cases, that may very well be the correct decision.

Decision-making is well known as an essential and important part of management, and it can be seen from the above that problem-finding and problem-solving are important because they lead to decision-making. Those initial thoughts suggest that there is a generic process. This is detailed below, step-by-step, first by looking at how to find a problem to be solved.

The Idea is Not New

The science (or is it art?) of solving problems has been known, as a generic item for a long time, usually within, for example, management, although rarely tackled by itself. However, Raybould and Minter, as an example of a work specifically on this topic, covered the art (or is it science?) of problem solving over 30 years ago [1].

PROBLEM FINDING

Stoner, Collins and Yetton have described problem finding as *Activities dealing with determining the existence and importance of problems* [2]. Indeed, this reference gives what the author has found to be the simplest, yet most explicit, explanation of the many facets of this topic.

Pursuing these activities becomes necessary, generally, under four situations: when there is a deviation from past experience; when there is a deviation from a set plan; when other people present problems; and when competitors outperform the manager's organisation [2]. The last is, fairly strictly, more related to managers than to engineers, while the third is the student engineer's situation mentioned in the abstract above. The first and second, as well as the third, are general situations faced by engineers in practice.

As an example of the first, the author recalls a high pressure reactor joint (20 MPa), with a 6 mm thick aluminium gasket, which began failing after a few weeks of service, although it had previously lasted the 12 months between internal inspections. That initiated problem-finding (why is this happening?) followed by problem-solving. It was found that a new supply of gaskets had been cut from a harder grade of aluminium that would not compress sufficiently. Having found that, the solution was quite obvious.

The second occurred in a carefully planned project, the progress of which was interrupted by a contractor's failure to deliver a critical item on time that, to some extent, blends into the third situation. The problem was found by comparing what would happen if the original plan were followed, with what should have happened, and was solved by juggling project sections into a different sequence.

It is interesting to note that sources quoted by this reference state that problem-finding is informal and intuitive, which suggests that many problems hit the finder in the eye (or elsewhere), rather than being hunted down laboriously. The two examples above tend to agree with that.

BUT BEFORE BEGINNING …

Before beginning with solving a problem, there are two questions to be asked and answered. They may seem absurd, but they are really quite important.

1. Is there a problem?

Should one begin by asking: What is a problem? Notes from a course that the author attended years ago gave: *it is a deviation from a planned or desired course of action*, which seems close only to production-type situations. More generally, a problem is caused by *things that are not as they should be*, or *something that has gone wrong*.

Believe it or not, some people, including engineers and managers, have been known to imagine problems where none exist, hence the standard joke about the lonely solution looking for a problem to fit it. The reasons for these types of relatively non-productive activities are usually related to politics-within-the-organisation, but it is also possible for the cause to be misunderstanding the information supplied.

2. Make sure what the problem is, is known quite precisely, before looking for a solution.

In other words, having realised that a question must be asked, and having framed what is believed to be the right question, just make sure that the right question is really, actually, being asked.

That is not intended to be humorous. There have been many cases of a problem-question being wrongly phrased with displeasing results. The wrong question will almost inevitably produce the *wrong* answer. A classic example of that comes from an English writer of about a century ago in a short story where he presented a fat (obese in today's language) man who told an Indian naturopath (again, using one of today's terms) that he wanted to lose *weight*, so he drank the dreadful mixture he was given and got what he *requested*. Was it what he *wanted*? *No*, what he wanted, really, was to lose size, or volume, and the result of this wrongly-phrased question was his weight was reduced to the point where he had to carry lead in his pockets, to keep him in comfortable contact with the ground [3]. This was written almost certainly as a humorous tale, but infers a moral that should be noted by anyone moving into management; even more so by engineers who should appreciate fully the difference between *weight* (or mass) and *volume*.

An engineering example may, in this present context, carry more weight that the above. The author was an engineer in a fertiliser factory where product loss was a problem. The problem-features that became embedded in the minds of the engineer and his counterpart, the production superintendent (who was also an engineer of the chemical persuasion), were as follows: the product was spilled from equipment, was not being collected manually and transferred to the reclaim tank, and, being water soluble, was often washed down the drain because the plant operators claimed (correctly) that the reclaim tank would not handle all the spilled product. So the engineers wrote a capital expenditure request for a bigger reclaim tank.

The two engineers felt more than moderately ridiculous when the manager refused to approve the request, with a direction that the equipment be fixed to reduce the spillages. There was a problem, but it was identified incorrectly.

3. Produce all the relevant and appropriate alternative solutions before thinking of choosing one.

This is the step of identifying the options; without these alternatives, one cannot move to the next step, which is the actual choice of which alternative to select.

A warning note should be sounded here. There have been many cases in which those involved have dashed off looking for answers in complexity where simple solutions will work. *Occam's razor* applies here: the simplest solution may be the best, not always, but often enough to make it worth consideration. For example, stopping the spillage was simpler (and cheaper) than installing a new and larger tank.

CHOOSING BETWEEN ALTERNATIVES

This stage of the overall activity has been described as: *Activities dealing with evaluating and choosing between alternative solutions* [2]. This very straightforward statement needs no further explanation or embellishment. Except, of course, it introduces the question: how does one make the necessary choice?

The following is suggested as choosing-steps (the first paragraph at each number is from an old reference; the author apologises for not being able to cite this reference with certainty, it is believed to be from Radford circa 1975, but the title has not been recorded).

1. Establish the objectives by thorough investigation of the results desired/expected and the resources available.

Or: where do you want to go? And how are you going to get there? Defining the objectives is so obviously important that if these questions cannot be answered, then one cannot proceed.

2. Classify the objectives in order of importance.

It is rare to find that there is only one objective, and the vital few [or one] must be sorted out from the trivial many. Then concentration can be applied to those vital few – or vital one, in some cases.

3. Develop alternative routes to the objectives, from which a choice can be made, consistent with the resources available.

That is, determine the available options that will lead, via available resources, to the objectives.

4. Evaluate the alternatives against the objectives.

This is achieved by testing the logical result of each alternative against the objectives. If this investigation finds a result that does not match the desired objective, that alternative must be discarded. There is only one test of an option: does it work out? If it does not, then it is not an acceptable alternative.

5. Choose the best alternative as a tentative decision.

This is, of course, something close to the actual decision-making process, but, at this point, no action is taken, only an assessment is to be made.

6. Assess the adverse consequences of this tentative decision.

There are almost always some adverse effects. Here, the person concerned can be helped enormously by having someone available who is a dedicated, even obsessive, nit-picker, the sort of person whom one normally finds painful to have around, but who can spot the pessimistic issues that are lost in the glow of enthusiasm radiating from everyone else.

STEP BACK A PACE

One factor stressed in the above is the importance of getting the *objectives* defined really clearly. In the real world, this can be rather difficult because objectives can be both subjective and objective, as well as obscure and elusive, for reasons described later. Ideally and actually in practice, as much as possible, the key starting point is knowing what the objectives are (ie *where are we going?*).

A sample specification of characteristics of objectives stated, it is believed, by Radford, should be as follows:

- Be well thought out and explicitly stated;
- Directly relate to the function of the organisation;
- Be stated in a form easily communicable to members of the organisation;
- Be defined such that methods of measuring performance in achieving the objectives can be readily devised;
- Be defined with sufficient precision such that the activities supporting one objective can be identified from those supporting another;
- Be stated so as to permit and encourage the postulation of alternative methods of achieving the objectives.

Having established the objectives to be met by solving the problem, and by choosing between the alternatives to find (what appears to be) the best way of finding that solution, one can now proceed further.

PROBLEM-SOLVING

Having made sure that there is a problem, that it has been identified correctly, that a range of possible solutions has been generated, that it is known what objectives should be satisfied by solving the problem, that the options have been compared with the objectives, then one is ready for the next vital steps: making a decision and implementing it.

The core reference used in this paper grouped four activities together as all contributing to solving problems [2]. The first goes back to problem-finding: *Activities dealing with identifying, defining, and diagnosing problems*; while the second relates to establishing what may be done: *Activities dealing with generating alternative solutions*. The third covers *Activities dealing with evaluating and choosing between alternative solutions*, and now one comes to the decision step: *Activities dealing with implementing the chosen solution*.

There is, actually, a very close link between problem-solving and decision-making; the two are very hard to separate from one another, and the author has a very strong impression that some writers refer to one when they mean the other. For example, Mukhi, Hampton and Barnwell state: *Another name for decision-making is problem-solving* [4]. Also, those who read this article will find that many of the items quoted from some of the referenced works start off by dealing with one (usually problem-solving) and then slide very smoothly into the other (decision-making), without saying so. There is no harm in that: it is only mentioned to stimulate readers' awareness.

THE RATIONAL MANAGER

There actually is a reference with the title, *The Rational Manager*, of which the earlier version will be used, being easier reading to bring out a few interesting points [5][6].

The first chapter begins with the question: *How do managers solve problems?* The answer given is the procedure outlined above, with the *caveat* that different people have different methods using the rational process, and in the example given it is observed that is largely due to the word *problem* meaning different things to each of the four players in the example, so that each jumps to a conclusion based on his own line of thought. The situation is further complicated (or, from the general manager's viewpoint, muddied) by each person connecting a different pair of the four facets of the overall problem.

The overall summary of this section brings these steps: the situation (what exists), the problems (refined from the situation), the priority problem (the vital one isolated from the relatively trivial many), the possible causes (reasons why), the most likely cause (further refinement), and the specific corrective action. After that, a decision is made.

Such a process appeals to the engineering mind, with the stronger left side of the brain steeped in logical, mathematically orientated procedures. There is no doubt that it works. But the author has developed reservations about it, based on a memory of his own behaviour when an engineering manager: having had the benefit of basic training, intensive and extensive, and a reasonable level of experience as a professional engineer and just about zero training in management, the author confesses to having initially been a poor-quality manager, which showed in the reaction to people bringing problems to him. The response was simple: he would automatically solve them!

That, really, is not the way to train the next generation of problem-solvers or, for that matter, anyone of any current generation. The *right* way to do it is to lead the person who has the problem to the answer, so that he/she finds it himself/herself. However, engineers do tend to accept the automatic-response indoctrination and need to unlearn it to succeed as people managers.

The benefits of the rational process cannot be denied, which is, definitely, the *science* method of solving problems. But is there an alternative?

AN ALTERNATIVE PROCESS

There has been emphasis, in the above, on getting alternative solutions from which a choice can be made. Now, on a different tack, two different and alternative *processes* or *procedures* will be compared by which those alternative solutions can be found.

The first is the one generally outlined above, the rational process. This appeals, somewhat probably, to engineers because they tend to think linearly, in straight lines. Whether that is by nature (inherited) or by nurture (their formal education) is debatable, but both observation of several hundred students as an academic, of many dozen colleagues as an engineer in industry, and of himself, has given the author a strong impression it is so.

So, a problem-solving process goes through these steps: define the problem, generate alternative solutions, evaluate and select an alternative, and implement and follow up on the solution, is eminently logical and suits a mind trained (or born) to like logical thinking processes.

There is nothing wrong with that, but the rational method has limitations. For example, it bogs down in ambiguous situations, or when a standard for comparison is not available, and its logic can lead to a wrong answer because it is linear; hence, it does not look at alternatives *off the beaten track*.

There is another way worth considering, which comes under the heading of the *art* aspect of problem solving, because it is different and can lead to answers not revealed by logic. This has been termed *creative problem-solving* [1][7]. Curiously, it requires *eliminating* some human features before it will work, whereas rational problem-solving requires the *application* of other features.

People are inhibited, hence hindered, in applying the creative methodology by conceptual blocks, mental barriers to creative thinking. These are given as:

- Constancy, being wedded to one way of looking at a problem or using one approach to define, describe or solve it. This can be caused by vertical thinking (similar to earlier-mentioned linear thinking) and using only one thinking language.
- Misplaced commitment, caused by stereotyping based on past experiences, or ignoring similarities between seemingly disparate pieces of data.
- Compression of ideas, looking too narrowly at a problem, screening out too much relevant data, or making assumptions that restrict thought direction.
- Complacency sums up lack of questioning, a bias against thinking, and because fear (of consequences), ignorance, insecurity or mental laziness blocks creativity.

If the problem solver can overcome these conceptual blocks then creative thinking can be applied, but (as remarked more than once above) this is difficult for engineers. Perhaps engineers should receive some training in one of the artistic endeavours, such as painting or sculpture? Perhaps the literature classes this author took, in which undergraduates were persuaded to write a short story, has made those now-graduate engineers more creative? In keeping with an earlier remark on this method, has this made these engineers more *artistic*?

Is there such a feature as *intuition* that allows some people to see the right answer without laborious reasoning? One writer explored this and has concluded that there is, and stated that *Intuition is knowledge gained without rational thought* [8]. The writer gave examples of how this process has worked and gave the impression that it can operate in two ways. One is the sudden fitting-together of a number of originally, seemingly-unrelated bits of information, a falling-into-place that occurs without mental effort, so that the answer to a problem is suddenly clear. The other is the sheer flash of inspiration, discovering a new and unexpected something that explains a problem.

A fine distinction, perhaps; but the vexed question remains: how can intuition be taught to engineering students?

ANOTHER METHOD

It seems odd that none of the references cited include, in the section on problem-solving, the *think-tank* method, bringing together a group and giving them the problem. The group should, preferably, be non-uniform, that is, not all engineers (for example) but a mixture of as many different types as possible. This author has seen this process utilised many times, several times in hazard and operability analyses of a process plant, in which members of several engineering disciplines, some operating staff, and others even including accountants, work through a process design to make it less hazardous and more operable.

Another, more informal example was observed in an industrial situation concerning a problem to work out how to reorganise production in order to gain a differently proportioned product mix. The group actually gathered in an office corridor and argued the matter out through a half hour, sifting points of view and almost reaching a conclusion by joint effort. What then followed was particularly memorable: the factory manager came by just as the group was hovering between alternatives, and his mere silent presence and nodding acted as a catalyst to bring the answer out of the group. The incident showed how *catalyst*-type managers rarely solve problems: their staff does that for them.

ENGINEERS AND THE DESIGN PROCESS

A fairly recent work by an American engineering academic seemed, by its title, to be a good source of information under that heading, but the opening of Chapter 2 has been found to oppose much of the previous argument [9]. Burghardt, curiously, takes the view that engineers are *creative* and *creatively solve problems*, and in the sense of his writing, those statements make sense because he has applied them to the design and production of new products [9].

The rational process is not mentioned. Alternatively, fitting in with the notion of creativity, there is a section on the left-brain-right-brain difference, and advice on how to overcome linear thinking – without using that term.

THE TIME PROBLEM WITH PROBLEM-SOLVING

It must be noted that some problems can be solved at a leisurely pace, with days allowed for gathering information, but others are severely time-constrained and must be solved in seconds, or less, perhaps more by intuition or guesswork than reasoning. In such a serious time-constrained situation, a manager can be excused if he/she solves the problem individually, instead of helping/allowing others to solve it, thereby letting others learn more by doing so.

AN INNOVATIVE METHOD

Actually, an innovative method might also be described as *irresponsible*, but it is often used by managers who have a problem. The technique is described in further after the example below.

The use was brought to life in a biography of a parson who worked in a series of churches in the USA through World War I into the 1930s [10]. His son's writing tells of the variety of residences that the family occupied, some good and some fair, but one which was downright awful with a dirt-floor and a continuously damp cellar, which caused concern for the children's health. Persistent requests to the church committee responsible for the property went nowhere. Finally, the minister and his wife asked for the cellar to be inspected. The head of the property committee obliged by calling to see what the problem really was all about. Unfortunately, the important visitor slipped on the stairs and landed on the muddy cellar floor. Hartzell Spence, the son, recorded, without elaboration, that a concrete mixer was in the front yard next morning.

The title for this technique is simply *make it someone else's problem*. This method can be used by an underling, by referring a problem *upstairs*, or by a more senior person handing it down to some poor lower-level person, who then receives the blame for what goes wrong.

A LIGHTER TOUCH

One cannot be continuously serious about anything connected with management, and this present topic is given a lighter side in a *Problem-Solving Flowchart*[1], which was circulated in a somewhat clandestine manner over a decade ago; perhaps it is still around, but these things do have a limited life and, therefore, current academics and others may not have seen it.

The chart begins with a question inferring that a problem may possibly exist: *does the bloody thing work?* If the answer is yes, then the advice is: *don't stuff around with it*, leading directly to the simple result: *no problem*.

The other side of the first question, with a negative answer, leads immediately to the question: *did you stuff around with it?*" What follows is, unfortunately, too much to reproduce here, by becoming quite complex and meandering through several paths including: *does anyone else know?* and questioning finally: *can you blame someone else?* (which relates rather well with the technique in the last section above), with a *yes* answer leading also to: *no problem*.

The flowchart is intended, one may readily conclude, to be humorous, but anyone reading it who has been through management in industry, or even in academia, can develop an uncomfortable feeling that there is more truth in it than humour – just as one does when reading the story about Pyecraft.

SUMMARY

There are at least two generic processes for solving problems: one that suits the engineering mind and the other that requires some effort to apply. Both should be given to undergraduate engineering students, and there is scope for a postgraduate subject.

Whichever is used, one needs to look at the constraints, the pros and cons, and the odds in whatever decision comes from the solution.

REFERENCES

1. Raybould, E.B. and Minter, Q.L., *Problem Solving for Management.* London: Management Publications (1971).
2. Stoner, J.A.F., Collins, R.R. and Yetton, P.W., *Management in Australia*. Sydney: Prentice-Hall of Australia (1985).
3. Wells, H.G. *The Truth about Pycraft*. In: Hammond, J., (Ed.), The Complete Short Stories of H.G. Wells. London: Orion Books (1998).
4. Mukhi, S., Hampton, D. and Barnwell, N., *Australian Management.* Sydney: McGraw-Hill Book Co. Australia (1991).
5. Kepner, C.H. and Tregoe, B.B., *The Rational Manager*. New Delhi: Tata McGraw-Hill Publishing Co. (1965).
6. Kepner, C.H. and Tregoe, B.B., *The New Rational Manager.* Princeton: Kepner-Tregoe (1981).
7. Carlopio, J., Andrewartha, G. and Armstrong, H., *Developing Management Skills in Australia.* Melbourne: Addison Wesley Longman Australia (1997).
8. Rowan, R., *The Intuitive Manager*. Aldershot: Gower Publishing Co. (1987).
9. Burghardt, M.D., *Introduction to Engineering Design and Problem Solving.* New York: McGraw-Hill (1999).
10. Spence, H., *One Foot in Heaven.* Sydney: Australian Publishing Co. (1944).

[1] Anyone not familiar with the flowchart, but interested in its instruction qualities, can get a copy from this author.

World Transactions on Engineering and Technology Education

A Call for Papers

Current events have impacted upon the arena of international conferences and academic travel, impinging on the freedom of intellectual movement to conferences and the like that are so important for the advancement of engineering education internationally and regionally and, indeed, the development of humankind now and into the future. To this end, the UNESCO International Centre for Engineering Education (UICEE) has established the *World Transactions on Engineering and Technology Education* (WTE&TE), which is open to everyone around the world who is interested in the progression of engineering and technology education. The *World Transactions* offers a safer and cost-effective alternative to conference participation.

So far, the first three volumes of the WTE&TE presented a range of papers from across the spectrum of engineering education and from around the world, including just over 200 very interesting and insightful representations from many countries worldwide. From this, it can be seen that the WTE&TE contribute strongly to the publication of engineering and technology education papers globally.

Therefore, a call for papers is made for the next issue of the WTE&TE, **Vol.4, No.1**. The very nature of the *World Transactions* is open to every facet of engineering and technology education and is not confined to traditional views about science, engineering and technology. As such, there are no overriding engineering or technology themes, but rather the overarching principle of the globalised expansion of engineering and technology education that is not confined to borders or regions; instead the WTE&TE seeks to benefit all those involved in the engineering and technology through the wider dissemination of knowledge.

The deadline for this issue is **31 March 2005**. Authors should indicate their interest as soon as possible. Additional information can be found at the UICEE's homepage under *World Transactions* at http://www.eng.monash.edu.au/uicee/

Interested persons should submit their original, previously unpublished papers to the UICEE for consideration to be included in the WTE&TE. Authors should be aware of the standard formatting structure, which will essentially be the same as for other UICEE publications. Papers are to be submitted in MS Word format in 10pt font, single-spaced, double column, and a **maximum of 4 pages** in total, including abstract and figures (additional fees will apply for extra pages). Fees are based on cost recovery for editorial and publishing work, and every submitted paper will cost $A450. Also, within the cost structure is the delivery of one copy of the WTE&TE per paper submission by airmail postage to anywhere in the world. Please note that all Australian submissions are subject to 10% GST.

The electronic kit for authors, incorporating standard formatting details and submission forms, covering copyright, will be supplied on request. Potential authors should notify their intention of submitting a paper at their earliest convenience and earlier submissions than **31 March 2005** will be particularly welcome. Further correspondence via e-mail should be directed to Mr Marc Riemer on marc.riemer@eng.monash.edu.au