Problem Solving in the Chemical Industry

R J CASEY
& M J FRAZER

Problem Solving in the Chemical Industry

R J Casey
Footscray Institute of Technology, Melbourne

M J Frazer
University of East Anglia, Norwich

Pitman

PITMAN PUBLISHING LIMITED
128 Long Acre, London WC2E 9AN

PITMAN PUBLISHING INC
1020 Plain Street, Marshfield, Massachusetts 02050

Associated Companies
Pitman Publishing Pty Ltd, Melbourne
Pitman Publishing New Zealand Ltd, Wellington
Copp Clark Pitman, Toronto

© R. J Casey and M J Frazer 1984

First published in Great Britain 1984

British Library Cataloguing in Publication Data

Casey, R.J.
Problem solving in the chemical industry.
1. Chemical industries—Case studies
2. Problem solving
I. Title II. Frazer, M.J.
338.4'766 HD9650.5

ISBN 0-273-02034-X

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording and/or otherwise, without the prior written permission of the publishers. This book may not be lent, resold, hired out or otherwise disposed of by way of trade in any form of binding or cover other than that in which it is published, without the prior consent of the publishers. This book is sold subject to the Standard Conditions of Sale of Net Books and may not be resold in the UK below the net price.

Printed in Great Britain by
Biddles Ltd, Guildford, Surrey

INDEX

adult psychology 5
Ausubel 3,11,17

brain storming 26

check lists 23,25
content free problems 1,2,20,21

de Bono 12,26
development theory 6

economic factors 15,23,45,94,103

function fixedness 10,20

Gagné 4

identifying problems 23,58,84,111
information processing 9
information, sources of 25,49,57

Kuhn 19

lateral thinking 26,27

means-end relationships 4

networks 11
Newell and Simon 9

Piaget 5
Polya 11,19
Popper 19

problems - developmental 32
- latent 33,37
- production 60,80,97
- trouble shooting 48, 110,116
- synthesis 40

problem solvers, successful 17
problem solving - barriers to 22
- definitions of 1
- factors in 23
- failures in 19
- models of 8-15
- obstacles to 21
- stages of 8-15
- strategies of 26
- techniques of 23

public analysts 116

Riegel 6

scaling up 77
synectics 26

target research 80,93
trouble shooting 48,110,116
tower of Hanoi 2

FOREWORD

The best way to become better at chemical problem solving is to practise - to learn by experience. But we can't do that all the time and so a good substitute is to learn from the experiences of others. In this book there are eight case studies describing how real problems in the chemical industry were identified and solved.

One of us (RJC) spent some days at each location talking to the people involved, finding out what they did, why they did it and what eventually led to success. We are most grateful to all those who helped us with this study. Their individual names are mentioned at the end of each chapter.

Chapter 1 is an introduction to chemical problem solving. It may seem rather theoretical, but we make no apology, because the process of problem solving cannot be studied without a firm and common base of language and ideas.

This book could be used in a number of ways and at different levels. We hope that it will enrich the teaching of chemistry in the sixth form and in colleges, polytechnics and universities, and that it will interest and inform professional chemists engaged every day in chemical problem solving. But above all, we hope that students will be inspired by the great variety of problems in the chemical industry, by the range of skills needed and by the enjoyment that comes from solving a chemical problem.

R.J.C.
M.J.F.

August 1983

此为试读,需要完整PDF请访问: www.ertongbook.com

CONTENTS

1 Problem solving in chemistry 1

2 Development of novel inorganic surface coatings 32

3 A novel synthesis of azelaic acid 40

4 Ignition of explosions in oil tankers 48

5 The electrowinning of uranium 60

6 The discovery of fluothane 80

7 Problems in fluorochlorocarbon development 97

8 An effluent disposal problem 110

9 A pesticide residue problem 116

CHAPTER 1

PROBLEM SOLVING IN CHEMISTRY

1. Problems and Problem Solving

1.1 Introduction The ability to solve problems is one of the most important skills of a professional chemist. This assertion is widely accepted by employers, teachers and students. They also express concern that for the majority of chemistry students the level of achievement in problem solving is low. There is an urgent need to improve the teaching of problem solving skills at every level of the education system. Unfortunately there seems to be a gap between the expectations of employers and the education chemists receive, because by and large, the problems of the 'real world' are not of the same type as those commonly found on examination papers.

The concepts embodied in the term "problem solving" cover a wide spread of meanings. Definitions range from the pragmatic view that problem solving is the process of "bridging a gap" between a "problem state" and a "solution state", through a range of views such as those of Duncker (1), Ausubel (2) and Gagné (3), towards conceptualistic-psychological views of Piaget (4), Riegel (5) and Perry (6).

1.2 Content-Free Problems Much of the research on problem solving is in the area of "content-free" problems and translation of findings of this work to the solving of the types of problems encountered by chemists in the real world is speculative. The "content-free" approach to the study of problem solving attempts to overcome variability in the background experience and knowledge of would-be solvers by setting a task which is, as far as possible, totally divorced from any discipline - specific information. Examples of this approach include 'The Pendulum Problem' (7), 'The Cancer Problem' (1) and 'The Pebbles Problem' (8). Other workers in this field (9-13) have used the

'Tower of Hanoi' puzzle.* Newell and Simon (14) have reported studies on chess playing and 'cryptarithmetic' of the type (DONALD + GERALD) = ROBERT, which led to their proposal of a computer programme model of human problem solving activity.

This "content-free" approach to studying problem solving concerns itself with the study of logical reasoning and thought, but any attempt to study chemical problem solving must include the added dimension of the chemical knowledge required. It is then difficult to achieve the same degree of model sophistication as is possible for content-free problems. In any case, a more pragmatic model may be more valuable for the practitioner of problem solving.

1.3 Variety of Views on Problem Solving The variety of meanings attached to the terms 'problem' and 'problem solving' poses difficulties. For example, Duncker (1) defined problem and problem solving as follows:

> "A problem arises when a living creature has a goal but does not know how this goal is to be reached ... Thus the 'solution of a practical problem' must fulfil two demands: in the first place its realisation must bring about the goal situation, and in the second place one must be able to arrive at it from the given situation simply through action."

In a general book on the methodology of solving problems, Jackson (15) has identified six basic Problem Situations, based on the subjective

---

* The 'Tower of Hanoi' puzzle is as follows:
Consider three adjacent pegs, A, B and C. On Peg A are n washers, of different diameters, arranged in decreasing diameter with the largest at the base of the peg. The problem is to transfer the array from Peg A to Peg C so that the size relationship stays the same. The rules are that only one washer may be moved at a time, and no washer may be placed on top of a smaller washer. All three pegs may be used as required. (It may be shown that the minimum number of moves for the transformation is 2^{n-1}. The complexity of the problem is readily variable by varying n.)

feelings of the perceiver:

(a) a feeling of dislike towards something or an urge to get away from it;

(b) a feeling of desiring something or an urge to achieve it;

(c) a feeling of dislike of one thing coupled with a desire for another, or an urge to change;

(d) an impression that there is a barrier to getting away from something;

(e) an impression that there is a barrier to some achievement;

(f) an impression that there is a barrier to change.

Attributes of problems, expressed in these ways, transcend disciplinary boundaries and are broadly applicable to all problems.

In contrast to definitions based on "feelings", educational psychologists like Ausubel (2) and Gagné (3) provide more restrictive definitions. Ausubel has defined problem solving as:

> "any activity in which both the cognitive representation of prior experience and the components of a current problem situation are reorganised in order to achieve a designated objective. Such activity may consist of more or less trial-and-error variation of available alternatives or of a deliberate attempt to formulate a principle or discover a system of relations underlying the solution of a problem (insight)".

The trial-and-error approach involves the solver in random or systematic variation, approximation, and correction of responses until a successful variant emerges.

The insightful approach, which is characterised by at least some implicit appreciation of the principle underlying the solution to the problem (as demonstrated by, for example, ability to transfer the understanding gained in solving the problem to a related problem), may involve either simple transposition of a previously-learned principle to an analogous new situation, or a more fundamental restructuring and integration of prior and current experiences to fit the demands of a designated goal.

For insightful problem solving, a necessary (but not sufficient) condition is the utilization of hypotheses incorporating means-ends relationships. Unless the hypotheses are of this type, the problem solving may, in fact, be merely systematic trial-and-error elimination of the available alternatives. Much of the classroom/academic approach to problem solving, particularly in mathematics and science, consists of solving problems by identifying them by type. This is a form of rote discovery learning and does not fall within Ausubel's definition of problem solving. Nevertheless, this approach is frequently used by teachers of chemistry and there would seem to be at least some value in teaching people to solve some problems by recognising them as examples of classes to which certain operations and/or principles are applicable.

Ausubel does make the point that no problem solving can be possible, no matter how skilled the learner is in discovery learning, unless he possesses the relevant background knowledge of facts, concepts, principles, etc. Both the factual content and the mental processes used in problem solving are important in any attempt to solve a chemical problem. All the technique and craft in the world is worthless to the would-be problem solver, unless he also has the necessary knowledge and information needed to solve the problem.

Gagné (3), in a substantially similar definition, views problem solving as taking rules and assembling them into superior rules (which are then learned) to solve the problem. A subsequent similar problem can be solved very much more easily because the solver has learned the superior rules.

Again, like Ausubel, Gagné makes the point that there is a distinction between the learning of the superior rules and any subsequent application to performance on the same class of problems. The novel experience is problem solving: the repetition is not.

> "Problem solving is the inferred change in human capability that results in the acquisition of a generalisable rule which is novel to the individual, which cannot have been established by direct recall, and which can manifest itself in applicability to the solution of a class of problems." (16)

In one sense, such definitions exclude a lot of what is generally called problem solving. In another sense, however, looking at problem solving as an insightful learning activity is very broadening since virtually all learning can then be seen as problem solving.

The work of Piaget (4) is often considered relevant to problem solving. In his terms, the resolution of Contradiction leading to Accommodation is problem solving. Some limitations of Piagetian psychology are:

(a) Piaget is concerned with movement towards positions of balance or stability or equilibrium and largely seems to ignore the causes of any imbalance. In other words, Piagetian psychology is concerned with equilibrium states, but not with the forces driving the system to seek those states.

(b) Piagetian psychology arises from a view of development from infancy through to adolescence and it would seem, at least intuitively, dangerous to extend this view to explain adult problem solving behaviour (unless one accepts a view that there are minimal differences between adults and adolescents).

1.4 The Psychology of Adults Firstly, do adults differ from children? Since most chemical problems are solved by adults it is quite important that any conceptual model should incorporate descriptions of adult behaviour. This has been explored by a number of workers. For example, Kohlberg (17) traces development of the individual through a series of levels:

Pre-Conventional Level	- children defer to authority to avoid punishment.
	- behaviour is governed by self needs.
Conventional Level	- individual defers to authority in order to be like others.
	- behaviour is governed by conventional modes of the peer group.
Post-Conventional Level	- individuals defer to their own consciences.

此为试读,需要完整PDF请访问: www.ertongbook.com

- behaviour is governed by derived or constructed standards.

Perry (18), and more recently, Kurfiss (19) have examined the development of American college students. Development is seen to proceed along a pathway from Dualism (black-white thinking), which is broken down as the student's ideas are challenged, to Relativism (where the student faces the task of developing intellectual tools to cope with the pluralism of ideas confronting him), and finally to a stage of Commitment (where the student accepts a need to construct, rather than passively accept, his own personal value system).

Perhaps the most far-sighted view of human psychological development over a life-long span is Riegel's Dialectical Theory of Development (5). Riegel's claim is that Piagetian psychology, which develops to the non-contradictory thinking of formal operations, although good for capturing a rich variety of childhood experiences, does not adequately represent the thoughts and emotions of mature and creative persons. Riegel has developed a theory, based on Hegel's notions of dialecticism. The conception is of man as an active agent who creates his world and is in turn created by it. Progression of events occurs along four dimensions: inner-biological, individual-psychological, cultural-sociological, and outer-physical. In dialectical theory, development represents coordination or synchronization of any two, and, ultimately, of all of these ways of progression. Crises occur due to asynchronies. Events occurring in one dimension can be triggers or causes of events in other dimensions. This is illustrated in Table 1 taken from Riegel's work (5), with the upper line in each row indicating negative outcomes and the lower line positive outcomes arising from the change.

Development occurs as a result of asynchronies (or crises or catastrophies) and contrasts. This development is seen as continuous - as soon as one development task or problem is completed, a new question or doubt arises within the individual or within society, and stable plateaus (such as Piagetian levels) are the exception. Mature cognitive development is characterised by tolerance for, and appreciation of, contradiction. The recognition of contradiction

Table 1. Riegel's Theory of Development

		INDUCED CHANGES			
		Inner-Biological	Individual-Psychological	Cultural-Sociological	Outer-Physical
TRIGGERING FACTOR	Inner-Biological	infection fertilization	illness maturation	epidemic cultivation	deterioration vitalization
	Individual-Psychological	disorder control	discordance concordance	dissidence organization	destruction creation
	Cultural-Sociological	distortion adaption	exploitation acculturation	conflict cooperation	devastation conservation
	Outer-Physical	annihilation nutrition	catastrophe welfare	disaster enrichment	chaos harmony

may be a prerequisite for defining problems, which in turn, may be a prerequisite for deriving their solutions. There is a distinction between "problem finding" (raising generic questions from ill-defined problems; divergent thinking) and "problem solving" (combining rules; convergent thinking); and the individual characterised as a "mature thinker" is characterised by the ability to find problems as well as to solve them: to both pose and ponder generic questions. True mature cognition is characterised by the search for contradiction, because contradiction is seen as the trigger for intellectual growth. That is, the problem solver becomes a problem seeker. Okun (20) has explored the instructional implications of this theory.

It would seem that Riegel's approach, with its emphasis on the dynamics of change, rather than the "resting points", is probably the most applicable to adult problem solving. Further, it would seem that adults are something more than "aged children".

1.5 Models of Problem Solving A pragmatic stance (15) is that a problem possesses two essential features - an Objective (the goal) and an Obstacle (that which is hindering attainment of the Objective). Problem solving then becomes the process employed in progressing to the objective (by overcoming the obstacle). (Figure 1).

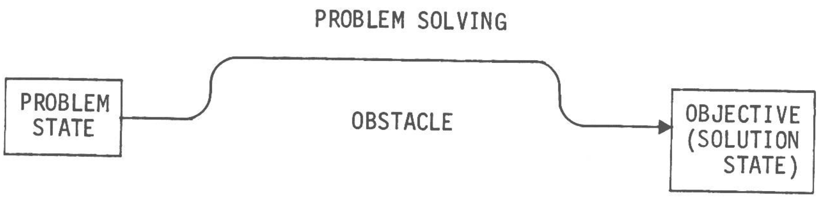
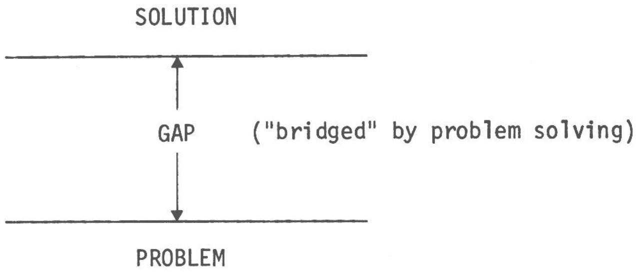


Figure 1: Problem Solving (15)

A similar pragmatic view (24) of problem solving is that it is the "bridging of the gap" between a problem and solution (Figure 2).



<u>Figure 2: Problem Solving (21)</u>

Various operational models have been formulated to describe the problem solving process. Newell and Simon (14) advocate an information processing model. The proposition is that the human problem solver can be viewed as a computer, and that human problem solving can be imitated by complex computer programs. A person's behaviour is seen as governed by a program organised from a set of elementary information processes. This sort of model is particularly useful in attempts to simulate human thought processes.

Other models proposed in the literature fall into various "stage-type" models, which can be fitted into four steps (22).

1. Preparation — the elements of the problem are studied and the implications investigated.
2. Incubation — the frustrated problem solver turns to other tasks without having solved the problem.
3. Inspiration — the solution suddenly appears in consciousness either spontaneously or when the subject intentionally returns to the problem.
4. Verification — the subject checks that his idea is in fact a solution to the problem.

This proposition dates from 1926, when it was put forward to explain the inventiveness of famous creators (23). There are, however, a number of difficulties, not the least of which is the select nature of the sample studied. Further, the proposition is not very appealing because of difficulties encountered when one considers the two key steps of incubation and inspiration. The nature of incubation is obscure. If it is merely the process of turning away from the problem, then we have all incubated many problems.

Perhaps in the incubation period the solver gets away from function-fixedness* and forgets implied assumptions posing constraints on the solution. Presumably if the problem is solved in a straightforward manner, without incubation or inspiration, then there can have been no problem at all! The model is most likely to be useful in depicting the routes to solutions of very difficult problems.

Merrifield, Guilford, Christensen and Frick (24) proposed the five stage model set out below.

1.	Preparation	the problem arises and is recognised as a problem which the solver is motivated towards solving.
2.	Analysis	the solver familiarises himself with the present situation and the desired goal.
3.	Production	through processes of synthesising information from the situation and forming relationships among this information, alternative solutions are generated.
4.	Verification	the alternatives are accepted or rejected.
5.	Reapplication	the accepted method of solution is applied to a similar situation to show that it is generalisable to a class of problems.

This model suggests that the solver first familiarises himself with all aspects of the problem. (Steps 1 and 2). He then draws upon information (from unspecified sources) to construct possible solutions (Step 3) which are then checked and accepted or rejected (Step 4). The fifth step, reapplication, would not seem to be an essential feature of solving a single problem, and indeed may, in specific instances, be part of the verification step. Certainly Gagné (3) and Ausubel (2) would not see reapplication as part of problem solving.

Gagné (3) presents a four step model.

---

* Function-fixedness describes the inability to conceive of other possible uses/functions of an object because of some over-riding influence of a more conventional use.

1.	Presentation of the problem	the solver is presented, either verbally or otherwise, with the problem to be solved.
2.	Definition of the problem	the solver defines the problem, that is, he distinguishes the essential features of the situation.
3.	Formulation of hypotheses	the solver formulates hypotheses which may be applicable to the solution.
4.	Verification of hypotheses	the solver carries out verification of his hypotheses, or of successive ones, until he finds one that achieves the solution he seeks.

Relating these steps to earlier discussion on problems, it is noted that only the first step is external to the learner/solver. The entities with which the internal processes deal are <u>rules</u>. When the problem is defined, rules have been recalled and selected. New rules are formulated as hypotheses and those which have been tested and confirmed are learned.

Ausubel and Robinson (25) have described a four stage model. In the initial stage the problem is presented to the solver. The solver, given the appropriate background knowledge, is able to relate the problem to his "cognitive structure" (the way his mind is organised) and understand the problem (Stage 2). In the third stage, the solver endeavours to fill the gaps by generating possible solutions using background information at his disposal and rules of inference. Finally, the last step is concerned with checking that the solution is, in fact, a solution to the perceived problem.

We have developed (21) a four stage pragmatic model of the problem solving process and applied it extensively to undergraduate chemical education (Figure 3).

A network approach is advocated by Polya (26,27). Mathematical examples are used to discuss general notions on problem solving and scientific method. Although the examples are mathematical, this should not deter chemists from reading Polya's books, for they are delightful and inspirational reading. A sequence of operations useful in problem solving are based around Polya's four stage model involving:

此为试读，需要完整PDF请访问： www.ertongbook.com