Training for optimising internal task transfer in the acquisition of process control skills

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TRAINING FOR OPTIMISING INTERNAL TASK TRANSFER IN THE ACQUISITION OF PROCESS CONTROL SKILLS

by

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A Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology

November, 1989

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Furthermore, I would particularly like to thank my parents for their financial support and also everyone else who helped in this respect. Finally, I would like to thank Miss Zoe, without whose moral support and encouragement I would not have been able to complete this work.

To Zoe I dedicate this thesis.
THESIS SYNOPSIS

The aim of this thesis is to investigate the acquisition of different elements of process control skills and how the transfer between task elements contributes to the acquisition of the overall task. Process control tasks are very complex cognitive tasks consisting of a number of subordinate task elements such as procedure-following, diagnosis, monitoring, whose execution must be planned carefully in order to meet the system goal. In the past, research emphasis has focused upon training these subordinate tasks separately, ignoring the possibility that performance at one element would benefit from or interfere with mastery of another. Understanding these possible 'internal transfer' phenomena will influence training design. It would also influence issues of work design, including allocation of functions, since tasks designed to enable practice of the constituent elements to support each other would counterbalance problems associated with infrequent use of skills in automated plants. This thesis has focused upon the development of training methods to optimise transfer of knowledge and skills, assisting trainees to integrate different task elements within the overall process control task they need to master.

The transfer of training literature was reviewed in order to identify major variables influencing transfer. To provide a framework for utilising previous empirical findings in examining transfer of complex process control skills, a model of Hierarchical Task Analysis was developed which described the task in terms of a limited number of operations and plans. A major hypothesis put forward in the thesis is that 'task elements with similar forms of plans and operations may prompt an individual to adopt similar cognitive processes and transfer will be observed'. The size of transfer, however, would be determined by the learning conditions under which the original task elements were acquired. To examine the influence of learning conditions upon transfer of task elements, four training methods were developed based upon a theoretical model of transfer which was integrated with the hierarchical task analysis.

A large scale experiment was conducted in order to investigate the effects of the four training methods upon learning two similar tasks, in the context of starting-up a distillation column. This task was simulated in a microcomputer. The two tasks were designed to share common task elements but were different in terms of the required product specifications.
Twenty-eight postgraduate students took part in a training course which lasted for eight hours approximately. The subjects were assigned to the following four experimental conditions: (i) the *procedures-group* which was provided with efficient procedures; (ii) the *analysis-group* which received additional explanations about the interaction of goals described in the procedures; (iii) the *model-group* which was provided with a structural model of the plant, but with no procedures; and (iv) the *practice-group* which learned the tasks by practice and which was used as a control condition. The model of learning was used to make transfer predictions and generate five experimental hypotheses which were tested in the main study; one hypothesis was concerned with the acquisition of the original task, two of them with the transfer of task elements and the other two with nonspecific transfer effects.

For a number of performance measures such as speed, control performance and economy of operation, the procedures- and analysis- groups performed the original task better than the other groups. The model-group was faster than the practice-group; however, their control and economy aspects of performance were equivalent. An 'in-depth' analysis of the control actions and verbal protocols showed that the model-group continued to experiment with the process, putting into practice the theory of plant which was taught to them.

Performance at the transfer task indicated that all groups performed better than the practice-group, which provides support for the hypothesis that 'task elements similar in form may prompt an individual to adopt similar cognitive processes and transfer may occur'. However, the procedures-group degraded its performance and appeared to be inferior to both the analysis- and model-groups, which may indicate that some kind of extrinsic information in the form of planning or conceptual knowledge would be required to optimise transfer. On the other hand, the analysis-group was faster than the model-group, but no significant differences were reported with respect to other measures of performance.

On practice with a successive transfer task of the same kind, the observed patterns of performance changed. Only the analysis-group was significantly better than the practice-group, the other groups having scored in between these two groups. This finding has highlighted the role of practice in an interactive learning environment provided by the plant simulator.
Although the experimental design attempted to control for nonspecific transfer effects by maximising the number of 'common' task elements between the original and transfer tasks, the individual differences observed and the changes in the kind of plans developed by trainees have indicated that such transfer effects have actually taken place. This was expected to occur to a certain extent, and two hypotheses had been formulated in order to examine this issue by looking into the types of planning and conceptual knowledge which supported transfer.

As it was expected, the analysis- and model- groups achieved higher nonspecific transfer scores than the other groups which were measured in terms of the amount of disturbance caused to previously established parameters and the number of questions answered in a questionnaire administered in the end of the study. An interesting result, however, was that the practice-group appeared to be better than the procedures-group in this respect; this may be accounted for by the fact that the former group was more actively engaged in learning the original task.

Finally, the thesis has investigated the transfer of the three subordinate goals common to both the original and transfer tasks. An important factor which has influenced the different degrees at which these goals were transferred was the degree of flexibility entailed in their performance. The thesis concludes with an evaluation of its own approach and suggestions for future research.
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CHAPTER 1

IMPORTANCE AND APPLICATION OF TRANSFER STUDIES IN THE ACQUISITION AND MAINTENANCE OF PROCESS CONTROL SKILLS

SUMMARY

This chapter examines the nature of process control skills and their similarity relationships which may give rise to transfer of learning. Although most of these skills are still required even in modern automated plants, previous research has examined them separately and in isolation from the overall task to be mastered. Thus, the issue of 'internal task' transfer has been neglected and many performance problems or benefits arising from practising the composite elements together were not addressed. More transfer studies, therefore, are required to serve this purpose. Finally, the importance of transfer studies expands beyond the optimal ways of sequencing instruction to the maintenance of skills with the introduction of new computer technology and allocation of functions between humans and computers.

INTRODUCTION

Process control tasks are very complex cognitive tasks requiring a repertoire of skills such as procedure-following, monitoring, diagnosis, compensation, and production optimisation. Acquisition of the overall task entails mastering the subordinate task elements as well as planning how to select and sequence these in appropriate orders. An important training issue then is how to develop learning conditions and to sequence instruction in order to enable trainees to integrate the composite elements into the overall skill, by taking advantage of similar behaviours entailed in various elements as well as coping with contradictory ones. The present research has sought to examine this issue of internal task transfer and develop training methods which would support acquisition of the overall skill.
Another type of transfer of learning is from the training situation to the real equipment or plant where the skill is needed. This type of operational transfer is receiving limited attention in the thesis, not because it is felt to be less important but because the 'internal task transfer' problem is in itself a large area warranting special examination. However, some of the results may also appear to be useful in the context of transfer to the real plant.

Justification for more transfer studies stems from the following three considerations, namely:

- Previous research into the behavioural models and training issues, reviewed in this chapter, has examined process control tasks in a 'fragmented' way and each task element was considered separately and out of the context of the whole task. Performance problems have emerged since different kinds of knowledge and skills were proposed for each task element, and the operator left unaided to integrate these in the context of the whole task.

- Empirical transfer studies have mainly examined relatively simple perceptual-motor tasks and text-editing skills and therefore, their findings have limited applicability to process control tasks where a significant component concerns the planning of subordinate task elements. A review and evaluation of these studies is presented in the following chapter.

- With the increasing introduction of artificial intelligence and control systems in modern plants, many skills have become redundant or infrequently practised and there is a risk of skill deterioration. There is a need, therefore, to identify elements within a task which are basic to the maintenance of general knowledge and skills and assign those to the human component or provide adequate practice in training simulators. Transfer studies are needed in order to contribute to the maintenance of skills with the introduction of automation.

All these arguments can justify further investigation into the acquisition and maintenance of skills through an 'internal task transfer' mechanism.
AIMS OF THE THESIS

The aim of this thesis is to develop a training methodology to analyse complex industrial tasks into a set of subordinate elements and to investigate forms of training which can optimise transfer between different task elements. To this extent, a method of task description will be elaborated in order to analyse complex tasks and identify similarity relationships between the composite task elements. To optimise transfer between these elements, a model of transfer of learning will be developed and tested in a large scale experiment. The training methodology will be illustrated in the context of learning a complex planning task, that of starting-up a distillation column.

THE NATURE OF PROCESS CONTROL SKILLS IN AUTOMATED PLANTS

The process control environment is one in which automation is an inevitable companion. There are two reasons which account for this, one concerning the physical and the other the cognitive capabilities of the human operator. Because process environments are hazardous and toxic materials are often employed, operators cannot come into physical contact with the process. Added to this, the complexity of the process parameters involved and their interrelationships impose heavy limits upon human cognitive processes justifying a degree of automation.

Plant automation, however, from easing physical and cognitive demands for the operator has now reached a point where most aspects of the process control task have been taken out of the hands of the operator and allocated to the control system. Many researchers have envisaged complete withdrawal of the human element from the process, with expert systems finding their way now into the detection and diagnosis of malfunctioning equipment (Andow, 1973; Lees, 1981; Lihou, 1981). There are, however, two premises which argue for continued inclusion of a human operator. First of all is the issue of technical feasibility. In order to automate process plants fully, the control system should be able to cope with any situation likely to develop which seems to be quite impossible due to the inherent limitations in the capacity of the machines which operate to a fixed set of decisions. Events which have not been foreseen by the designer call for a competent human operator. However, even if total automation of the process was feasible, the second consideration
that of the cost might preclude its implementation. Therefore, it is essential that the nature of process control skills and their interrelationships are considered in the context of the new computer technology.

Earlier studies into the process control were concerned with making sense of the variety of task responsibilities of the process operator. Crossman (1960) listed six categories of process control activities: manual control, operating sequences, process control, fault detection, communication and emergency drills. With the increased automation, the content of the process operator’s task has changed. de Jong (1964) and Rasmussen (1974) provided a classification scheme of process control tasks in modern plants based on the different responsibilities of the human operator, rather than the required kinds of knowledge and skills. Three phases were mainly distinguished: (1) Normal operation; (2) Abnormal operations which include failure detection, diagnosis and corrective action; and (3) Switchover operations such as start-up and shutdown operations. Computer support and performance problems associated with automation are described below for each phase in order to define the role of the human operator in modern process plants and the required skills.

Normal operation

Under normal conditions, the process which has been brought into the specified operating conditions is controlled by a human operator who is 'trimming' various process parameters in order to maintain them within certain limits. The responsibilities of the operator under normal operation will depend upon the levels of automation in each plant. In plants with low levels of automation, the operator may have to control manually various parameters and maintain them on target values. At moderate levels of automation, a number of control loops take over the manual control of process parameters and the operator has to adjust their setpoints or target values in order to satisfy product specifications and run the plant safely and in an economical fashion. Several operators with different ideas of the optimal operating conditions may experiment with the process and the adjustment of the set points at shift take-over, which contributes to their understanding of the process behaviour.

At higher levels of automation, the setpoints of the control loops will be calculated by the system itself and automatically brought into correspondence with the product specifications. This will leave the operator with few
opportunities to exercise manual control skills which may deteriorate to a large extent. On many occasions, however, the management may wish to change the product specifications and require the human operator to take over manual control and bring the process to a different operating state. This will set a difficult task for the operator who has lost a great deal of his control skills, particularly refinements of gains and timing, and may result in the process being set into oscillation. Therefore, even in highly automated plants there is scope for a human operator who will have to maintain his control skills and perform effectively on occasions where a change in the product specifications is desired.

Switchover operations

Start-up and shutdown operations are characterised by a complex sequence of process manipulations following a fixed procedure. The operator should carry out the individual manipulations after checking that the necessary conditions are fulfilled. In automated processes, standard start-up and shutdown procedures have already been prescribed in a way which would allow sequential controllers to perform the task (Welbourne, 1965). However, there are still cases where unpredictable events can occur for which procedures have not specified satisfactory manipulation, and this calls for a human operator to take over control of the process.

The same kind of performance problems will be encountered by the operator as in the case of changes in product specifications. In addition, manual start-up or shutdown operations demand cognitive skills and particularly an ability to generate successful novel strategies based upon a good knowledge of the current system state. Research into operator's working memory by Bainbridge (1972) has shown that a good knowledge of current process states requires not only raw data displayed on the control panel but also elaborated data which are the result of making predictions and decisions about the process. This information takes time to build up and the operator who takes over from an automatically controlled plant and has to do something quickly, needs to have available reliable automatic responses. This requires frequent practice of start-up or shutdown responses either in on-line control or on a high fidelity simulator. It appears then that these sorts of skills will be needed even in automated plants.
Failure detection and diagnosis

Probably, the most frequently exercised operation in modern plants is failure detection where the operator has to detect a significant departure from the specified operating conditions of the process. In complex modes of operation, the human monitor needs to know the correct behaviour of the plant for each particular stage of the process and compare it with the behaviour observed. In many automated plants, the control system can display target values and currently appropriate tolerances in order to assist the operator in monitoring the process. On other occasions, monitoring can be done by the control system itself which compares target values and tolerances with measured data representative of the current state of the process and gives a warning signal to the operator. However, this does not get round the problem but only raises the same ones in a different form. Bainbridge (1987) commenting on the ironies of automation has identified two potential problems with both types of automated monitoring systems. A major problem arises when the automatics are not working properly so that the operator cannot trust the target values and tolerances displayed. The second problem concerns the monitoring of the automated monitoring system itself, which is there because it is supposed to monitor parameters and take real-time decisions to accurate criteria better than humans do. The operator is set an impossible task that of monitoring an automated system which monitors the process faster than him. It appears then that monitoring of an automated plant is a demanding task and requires knowledge and skills which can be developed in the context of other process control operations.

After a deviation from the normal conditions has been detected, the operator will have to identify the malfunctioning process or control system. Diagnosis of plant failures is not a frequent situation and is usually assigned to the human component. In modern plants, computerised 'alarm' systems (Andow, 1973) have been designed to use the way in which faults propagate through the plant in order to help the operator interpret alarm information and make inferences about the cause of failures. However, the computer by combining and configuring alarm information deny the operator information which is useful for diagnosis. The problem may be exacerbated when a failure or combination of failures which have not been foreseen by the designer are incorporated in the alarm system. In view of this problem, some authors (Lees, 1980; Welbourne, 1965; Patterson, 1968; Andow, 1973) have suggested that the
alarm system should effect diagnosis of individual faults, employing as a basis proceduralised algorithms or decision trees incorporated into the system. But automatic diagnosis systems cannot cope with novel abnormal states, since they are designed to operate to a fixed set of decisions.

This situation has led to the operator being required to solve only the more rare and difficult faults without having had recent diagnostic experience. Studies in the training of diagnostic skills by Shepherd (1980) and Duncan (1981) have shown that experienced operators encounter difficulties in diagnosing novel faults particularly when they employ 'pattern recognition' strategies. More recently, a study by Reiersen (1985) has shown that diagnostic skills are not retained when they are not exercised frequently. It seems that automation, by removing the easy parts of the diagnostic task has made the difficult parts even more difficult.

Corrective action

When a failure has been identified, the operator should take corrective action to either recover the abnormal situation or to prevent fault propagation to initiate the automatic shutdown safety system. In both recovery and fault elimination tasks, a decision must be taken based upon detailed knowledge about the trend of the operating conditions resulting from the failure, and the consequences of the suggested corrective actions on the process. Sequential procedures aimed at assisting operators in this task may encounter the same problems as the start-up and shutdown procedures, and this calls for a human operator who is competent in both manual control and cognitive skills to supervise the process.

POTENTIAL IMPORTANCE OF TRANSFER STUDIES

From the above discussion it appears that the human operator is called upon to perform most task elements of the overall process control task, although with increasing levels of automation practice is constrained to situations where the automated system cannot cope with unforeseen events. Facing the risk of skill deterioration from infrequent practice (Annett and Piech, 1981), we can examine whether various task elements could serve to maintain general knowledge and skills about the process which is useful in supporting
performance of other task elements and counterbalance problems of infrequent use of skills. In this way, performance of a task element can be supported even when the operator is engaged in performing other task elements. This will be enabled when these task elements entail compatible behaviours which can be exercised in the context of either tasks.

This is precisely the purpose of the transfer of training studies, which are concerned with the development of learning conditions that enable trainees to benefit in the performance of a task element from previous experience with another one. The term 'transfer' refers to the carry over of knowledge and skills to other contexts of application.

The methodology adopted by many transfer studies usually involves two main stages. In the first stage, competent behaviours for two tasks are proposed and subsequently modified to the extent that they become compatible and support performance of both tasks. On many occasions, however, this is not possible, and the entailed behaviours are conflicting; in this case, the two tasks should be practised separately. The second stage involves the development of learning conditions which enable trainees to become aware of any common elements between different tasks that they have to master.

Transfer studies can contribute to three broad areas of research in process control, namely:

(i) Development of optimal sequences of instruction which can reduce the amount of training time and cost. For instance, if two task elements require similar types of skills and knowledge they can be taught together so that practice of one element enhances learning of the following one. Conversely, if two elements require conflicting behaviours trainees can be allowed to practise the tasks separately until their behaviour becomes automatic and one task does not interfere with the other. The study of transfer of training extends beyond the transfer of different types of process activities i.e. control, diagnosis etc., and includes transfer within each type of operation such as transfer from an intermediate to a final stage in the task of starting-up a chemical plant.

(ii) Development of versatile skills. When the trainee becomes able to modify and adapt his old skills to a new situation, he acquires generic skills which can apply to a variety of situations. In many cases where a person's status in the plant and his self-esteem depend upon his level of skill, versatile skills can
contribute to job-satisfaction and keep operators more attentive and more interested.

(iii) Development of criteria for the allocation of functions between human and computer. With the introduction of artificial intelligence to control systems, transfer studies can identify elements within a task which are basic for maintaining general knowledge and skills and assign these to the human component or specify conditions of practice in training simulators. This perspective shifts the emphasis from the traditional 'Fitts list' approach - which compares the capabilities of humans and computers - to the consideration of how to integrate the two components in a way that the computer always serves the purpose of transfer and maintenance of skills.

Unfortunately, the importance of transfer studies was only recently recognised and there is a lack of methodologies for systematically studying transfer between different elements of process control skills. Research into the behavioural models and training methods has 'compartmentalised' the overall process control task and has examined each task element in isolation from the others. This issue is elaborated further in the following sections.

RESEARCH INTO THE BEHAVIOURAL MODELS OF PROCESS OPERATORS

Two invaluable sources of research into the operator's behaviour in process control are the reviews by Edwards and Lees (1973, 1974) which cover areas such as human factors principles, human error, man-machine system reliability, and developments in computer control. The bulk of this work is specific and applied and its contributions to the understanding of the kind of knowledge and skills required for process operations is not obvious.

Another prominent line of research (Crossman, 1960; Crossman et al., 1964; Crossman and Cooke, 1962; Beishon, 1969; Bainbridge, 1974) examines mental aspects of the operator's behaviour mainly because of the insights into cognitive psychology that process control tasks provide, and thus remains neutral with respect to any specific area of application. This work is primarily concerned with the observation of performance of experienced operators in simulated plants and the inference of their thinking processes by using a
variety of techniques such as activity sampling (Beishon, 1969), questionnaires (Kragt and Landeweerd, 1974) and verbal protocols (Bainbridge, 1974).

Central to most behavioural models of the process operator in the above research is the assumption that the operator possesses a mental model of the process which is supposed to guide display scanning (Moray, 1981), anticipation of future system states and formulation of plans for action (Crossman and Cooke, 1962; Kragt and Landeweerd, 1974; Bainbridge, 1984), and finally, detection and diagnosis of plant failures (Rasmussen, 1981). However, the concept of mental models has been given a variety of definitions so that it is quite difficult to differentiate this concept from that of 'knowledge' in general. Rouse and Morris (1986) who reviewed the literature into the 'black box' of mental models concluded that, in most cases, these were used as a substitute for the general concept of 'knowledge'. Such a definition is not particularly useful. It seems, however, that many researchers would incline to agree that mental models of the process refer to what has recently been called how-the-system-works knowledge, that is, knowledge of the process mechanisms and dynamics which accounts for the operator's knowledge of the causal-effect chains as well as size and timing of effects (Rasmussen, 1986). Other types of operator's knowledge can include strategies, goals and plans for action, rules of thumb and so forth; these are reviewed and elaborated in the description of the 'transfer model' in chapter 5.

A great deal of research has been devoted to the study of various aspects of 'mental models' of the process and their potential use in controlling, monitoring and diagnosing the process. Wickens (1984) has reviewed the relevant research and suggested that a 'dichotomy' can be drawn between control, on the one hand, and detection and diagnosis on the other. This has even strengthened a tradition to isolate task elements and examine them out of the context of the whole task, and to some extent has restrained the conduct of any transfer studies.

Frequently cited evidence of the postulated 'dichotomy' between different process control elements is a study by Landeweerd (1979), which found positive correlations between control performance and verbal-causal models of the process as well as between diagnosis and visual-spatial images of the process. One difficulty in interpreting this experiment is the small correlations found ($r=0.18$ to $0.31$) and the indirect measure of quality of mental models which could be any cognitive ability (i.e. intelligence) rather than the one claimed.
Other examples of this 'dichotomisation' include: a study by White (1981) which found that control behaviour and monitoring are affected in different ways by certain task variables such as display structure, type of disturbance and task requirements; a study by Moray (1981) which concluded that normal control is associated with sampling of weakly correlated parameters, whilst detection and diagnosis is associated with highly correlated ones; and a study by Kessel and Wickens (1982) which found that detection of dynamic system failures did not help operators in the control of these systems.

One should probably recognise the flexibility of performance for each process control task. It is conceivable that control and diagnosis, for instance, may be performed in ways which entail different behaviours as well as in ways which may entail compatible ones. The fact that in the above experiments the observed behaviours were not compatible may well have to do with the experience of the examined operators and the type of training they received prior to their test performance. Other types of training may encourage trainees to adopt more compatible behaviours which can facilitate transfer. Finally, it is worth pointing out that transfer is not always in both directions as it appeared to be the case in Kessel and Wickens (1982) study, where subjects with experience in control did a better monitoring job than subjects who were originally trained in monitoring the system.

However, a number of researchers have recognised the fact that different task elements in process control may share 'common elements' and underlying psychological mechanisms. Research by the RISO group (Rasmussen, 1981; Goodstein, 1982; Rasmussen and Lind, 1981) has claimed that operators are engaged in some sort of identification of the current process state during most aspects of the process control task. The identification of the process may serve different goals specific to different task elements such as: (i) to decide whether the process is ready for an intended action; (ii) to confirm that an action has brought the process to a target state; and (iii) to compare the current process state with the ideal or desired ones in the cases of detection and diagnosis. The boundary between routine identification (types i and ii) which is characteristic of normal operation, switchover and corrective operations and identification of abnormal states (type iii) is ill-defined and depends upon the operator's prior experience.

It seems then, that performance at a task element may benefit from practice of another element as far as operators are involved in some sort of process
identification in both tasks, based upon a good knowledge of plant theory and dynamics. This raises the issue of training operators to become aware of any common elements between different types of process identification and optimise transfer effects.

Bainbridge (1978) has argued that 'manual takeover involves some fault diagnosis which also depends upon knowledge of plant dynamics and mechanisms'. During manual control the operator may overshoot certain process parameters such as temperature or pressure, and subsequently become involved in identifying his inefficient control actions which gave rise to that particular symptom state. The same behaviour is entailed when the control action is taken by the control system and the operator has to diagnose the causes from the observed symptoms.

It is often claimed that fault elimination and recovery operations may be distinct from diagnosis since the latter operation requires knowledge of plant mechanisms only, whilst the former ones require additional knowledge of size and timing of effects. This is generally true when faults can be identified from the steady state appearance of the control panel, and waiting for the steady state is acceptable. If fault diagnosis involves identifying the propagation of faults throughout the plant, then operators need to possess some knowledge of the gains and timings which are also required in fault elimination and recovery. Indeed, Bainbridge (1984) argues that 'operators use the same type of information structure during diagnosis as they do during control and one which the focus of attention is on process parameters rather than process equipment'.

It seems then that many studies into the behaviour of operators have fragmented the whole task into a number of task elements and examined them in isolation from each other. Recent studies by Bainbridge (1978) and Rasmussen (1981) have argued that different process control tasks can support each other when they entail similar behaviours. In order to enable such transfer the operator should be trained to become aware of any common elements between tasks. Studies in the training of process control tasks are reviewed below to examine the extent that this aim has been achieved.
TRAINING METHODS FOR PROCESS CONTROL SKILLS

A contrasting approach to the investigation of *behavioural models* in process control tasks, focuses on the *training conditions* required to enable operators to perform effectively these tasks. This line of research (Annett et al., 1971; Duncan, 1974; Shepherd, 1976) employs *Task Analysis* to redescribe the task of interest into a number of subordinate operations and plans, and prescribes training conditions which can ensure competent performance of the whole task.

Contributors of this line of research have tended to focus on the issue of diagnosis training (Duncan and Shepherd, 1975; Duncan and Gray, 1975; Shepherd et al., 1977; Marshal et al., 1981), at the expense of the training for other aspects of the task i.e. detection, recovery, and normal operation. This bias towards diagnosis training can be understood in terms of the greater frequency with which operators are involved in fault diagnosis, and the high cost and long running-time of plant simulators that favour diagnosis training which concentrates on failure situations only (Shepherd, 1981).

It seems then, that training issues have isolated the task in question and investigated it out of the context of the whole task. In view of the fact that even automated plants require operators to practise a variety of task elements together, training regimes appear to be incomplete, since they have not considered any positive or negative transfer of learning that might arise when these elements are practised together.

It is conceivable that while fault diagnosis, for instance, may be trained effectively by teaching the operator a set of 'rules of thumb' (Shepherd et al., 1977), a task such as the recovery of a disturbed process may benefit from some knowledge of process structure and functioning, which may enable the operator to generate hypotheses for potential effects on the process. The question then arises, as to what extent different optimal conceptions of the plant interfere with one another, when the operator practises both tasks in real life situations.

There is scope then for research to examine how several task elements requiring similar or different kinds of strategies and process knowledge could be trained in the context of the whole task. Taking again the above example, it would appear that the two possibly different conceptions of the process may support or impair performance of the various task elements depending on the way these are trained. A *hypothesis generation strategy* based upon plant knowledge may
be very effective for the recovery task, however if this strategy substitutes completely a heuristics-based strategy in the diagnostic task, performance may degrade (Rasmussen, 1981). On other occasions, it may be possible for a hypothesis generation strategy to enrich a heuristics-based strategy when these strategies are learned and applied 'properly'. If a set of 'rules of thumb' can be evolved by trainees who have actively learned knowledge about the process structure and functioning (Reiersen, 1985), then a hypothesis generation strategy applied to the recovery task could refine their knowledge and assist them in perfecting their heuristic-based strategy for their diagnostic task.

Therefore, when various task elements are examined in the context of the whole task, any interference likely to be caused by different types of knowledge and skills will be minimised.

A similar situation will arise when we are concerned with the transfer of training within the same kind of activity. For instance, the task of starting-up a plant may involve mastery of subordinate task elements such as 'establishing levels', 'building-up temperature profiles', 'adjusting reflux flows' and so forth. Transfer studies would investigate the extent that two task elements can be supported by similar forms of performance. This raises the issue of part versus whole task training methods. When two tasks are supported by similar behaviours, they can be practised together as a 'whole'; when they entail conflicting behaviours, they can be practised separately as different 'parts' of the same overall task until their performances become automatic and any interferences are minimised.

Studies on the issue of part versus whole task training have examined a variety of factors which could be used as a criterion for choosing between alternative methods of training. More specifically, Naylor and Briggs (1963) have addressed the issue of task organisation and complexity, Annett and Kay (1956) have considered the nature of task interrelationships, Stammers (1976) has investigated the linking between parts in serial tasks and the point of changeover from part to whole, and Shepherd and Duncan (1980) have studied combinations of part and whole methods.

The new dimension that transfer studies can contribute to this issue is the degree that two or more tasks can be supported by similar types of behaviour. Transfer studies can describe optimal instruction sequences where subsequent
tasks can benefit from mastery of previous ones, and this can reduce cost and duration of training.

**CONCLUSION**

The specific conclusions reached from the foregoing review are:

- Most process control skills are still required even in highly automated plants in one form or another.
- Different tasks in process control may share 'common' elements and underlying psychological mechanisms.
- Research into the behavioural models and training methods have been carried out in a 'piece-meal' fashion and each task element has been considered out of the context of the whole task. Therefore, the issue of 'internal task transfer' has been avoided and the operator left unaided to integrate these elements.

These conclusions point out the need for a transfer model which will identify similarity relationships between different elements and optimise transfer of knowledge and skills between them. The training methodology which is developed in chapters 3, 4 and 5 will serve this purpose.
CHAPTER 2

LITERATURE REVIEW AND CONSIDERATION OF A PROPOSED APPROACH TO TRANSFER STUDIES

SUMMARY

Previous studies on transfer of training are reviewed in order to develop a framework of the major task variables influencing transfer, their inter-relationships and the ways they produce transfer. This framework will help us organise our knowledge about transfer and consider various conceptual models of psychological processes which can account for transfer phenomena.

Because the significance of many transfer effects is partly affected by the different experimental designs and transfer measures employed, these are reviewed first. Two major categories of transfer are identified, namely, specific transfer concerning task similarity relationships of stimuli and responses and nonspecific transfer which includes transfer of concepts and principles, transfer of strategies, learning-to-learn, warm-up and bilateral transfer.

Conditions of practice such as degree of original learning, variety of practice and distribution of practice over time are also examined in their capacity to influence both specific and nonspecific transfer. Finally, conceptual models which investigate the mechanisms of transfer are reviewed in order to understand the nature of various types of transfer.

This chapter concludes with the approach adopted in the present thesis to investigate transfer effects, which is further illustrated and developed in the following three chapters.
INTRODUCTION

Many educational psychologists believe that the major objective of learning lies in its use and application to novel situations. The facilitation of learning in new situations by previous learning is referred to as transfer of training. In the previous chapter, we considered many instances where knowledge and skills in operating a process plant can carry from one task element over to another and support performance of both. When performance at one task enhances or depresses retention of a previously mastered task, there is said to be retroactive transfer. When the effect of transfer is on subsequent learning, the term proactive transfer is used. Transfer of training refers to both cases where the learning of one skill affects retention of a previously acquired skill, and where it affects the acquisition of new skills.

Historically, the units of transfer process have been thought to be rather broad mental faculties such as memory, reasoning, manual dexterity and so forth. Such faculties were considered as being trained and made more disciplined by studying different subjects such as Latin, mathematics, philosophy etc., in the same way that muscles strengthened by exercise can be used later for any manual work. This is the traditional doctrine of formal discipline. If training in one skill favourably influences the acquisition of another, there must be something common to both activities. It is, however, too much to suggest that the common component to both activities is the whole system called the faculty of memory. Unfortunately, many early studies of transfer failed to specify the precise variables producing transfer, even though positive or negative transfer may have been observed.

Contrary views about similarity of stimuli and responses involved in successive tasks have been expressed by Thorndike and Woodworth (1901) in the theory of identical elements. Skills transfer from one activity to another only to the extent that the two involve the same stimulus-response associations. However, Thorndike believed that identical elements may also consist of such common factors as similar techniques, general principles, thoughts about aims and so forth.

This theory has marked an effort of more analytical studies of transfer to analyse the fundamental dimensions of transfer. Transfer tasks can vary with respect to many dimensions such as the degree of similarity between tasks, which can be further analysed into stimulus similarity and response similarity,
variety of tasks, complexity of task etc. In summary, research in transfer of training has shifted to a more analytical approach aimed at determining why transfer occurs - that is, discovering the precise variables that influence transfer, whereas previously it was more concerned with whether transfer did occur.

Current issues and problems in transfer of learning can be conveniently classified in five major areas as these were identified by Ellis (1965), namely: (i) research methodologies dealing with various transfer designs and transfer measures; (ii) studies to specify major variables influencing both specific and nonspecific transfer; (iii) conditions of practice which facilitate transfer of task variables; (iv) conceptual models of transfer which attempt to integrate knowledge about transfer; and (v) educational technologies to apply our knowledge of transfer to various educational and training contexts. Only the first four areas will be discussed in this chapter, while implications for educational technologies will be made in the chapters to follow.

METHODOLOGIES FOR THE MEASUREMENT OF TRANSFER

Empirical findings of different transfer studies can depend upon the way in which transfer was measured. The various designs and measures of transfer are discussed below to help us understand and compare the results of several transfer studies. Since most studies are concerned with specific transfer, an effort is made so that the experimental design can control for nonspecific transfer effects.

Transfer designs

In order to determine what precisely is carried over to the transfer task, the experiment must be planned with the utmost care. Generally, transfer experiments are carried through two parts, the training period on the original task and the test upon a transfer task. Information on transfer effects is obtained by comparing test scores of matched experimental and control groups on the same transfer task. A summary of the more frequently used transfer designs is shown in table 2.1.
The simplest transfer design is the first one, in which only the experimental group receives preceding training while the control group rests. The main weakness of design-1 is that any differences between groups may be the joint product of specific and nonspecific associations such as warm-up or learning-to-learn etc. To arrange proper control for nonspecific transfer, another design-2 can give subjects of the control group nonspecific practice by allowing them to perform a task A1 equivalent to task A on all counts, excluding the intended similarity relationship between tasks A and B. Thus, any group differences in the performance of the transfer task B will be the effect of specific similarity relationships between tasks A and B.

Table 2.1.
Summary of transfer designs.

<table>
<thead>
<tr>
<th>Design</th>
<th>Group</th>
<th>Fore-test on transfer task</th>
<th>Training at original task</th>
<th>Test on transfer task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experimental</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>none</td>
<td>(Rests)</td>
<td>Learn B</td>
</tr>
<tr>
<td>2</td>
<td>Experimental</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>none</td>
<td>Learn A1</td>
<td>Learn B</td>
</tr>
<tr>
<td>3</td>
<td>Experimental</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B1</td>
</tr>
<tr>
<td>4</td>
<td>Experimental</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>none</td>
<td>Learn B</td>
<td>Learn A</td>
</tr>
<tr>
<td>5</td>
<td>Experimental</td>
<td>none</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>and Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Experimental</td>
<td>Learn B</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Learn B</td>
<td>(Rests)</td>
<td>Learn B</td>
</tr>
<tr>
<td>7</td>
<td>Experimental</td>
<td>Learn B</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control-i</td>
<td>Learn B</td>
<td>(Rests)</td>
<td>Learn B</td>
</tr>
<tr>
<td></td>
<td>Control-ii</td>
<td>(Rests)</td>
<td>Learn A</td>
<td>Learn B</td>
</tr>
</tbody>
</table>
Design-3 keeps the original task the same for the two groups and introduces variations in the transfer task i.e. B and B1. This design has also the advantage of controlling for nonspecific transfer, so that group differences in the performance of the transfer task can be attributed to specific features of the transfer task itself. The chief difficulty, however, is to ensure that tasks B and B1 are equally difficult in the absence of task A learning, so that transfer effects are not confounded by inherent differences in the performance of tasks B and B1. Examples of this type of design can be seen in the work of Gibson (1941) and Hamilton (1943).

Design-4 is one in which half the subjects learn task A followed by B and half the subjects learn the reverse sequence. This type of design has been employed in studies of transfer of text-editing skills (Polson et al., 1986; Ziegler et al., 1987). One problem encountered with this design is that we must ensure that tasks A and B are functionally equivalent, that is, the similarity relationships between tasks are such that it is immaterial which is learned first and that practice effects from A to B are the same as from B to A.

The experimental designs discussed so far may be classified as following the method of successive practice in which two or more unfamiliar tasks are practised by naive subjects, perhaps for the first time in the laboratory. Another type of design (type 5) is used exclusively for studying the temporal course of transfer in which groups learning at different time intervals may serve as controls for each other (Bunch and McCraven, 1938; Ellis and Burnstein, 1960).

The last two designs which centre upon the extent that practice with a task A alters the level of mastery of a previously learned task B, follow the procedure known as the fore-test-post-test design. In the design-6, two groups are given practice with task B until it is partially mastered to a certain degree measured by a fore-test. The experimental group receives subsequent training on task A whilst the control group is resting, and finally both groups take an after-test on task B. Pre-test scores enable us to form two exactly matched groups, and by subtracting the control group improvement from that of the experimental group we can obtain a net transfer effect.

It has been argued against this method that so much learning may be accomplished in its fore-test stage that only insignificant transfer gains are likely, and the design may not be able to detect them. Kothurkar (1985) has
suggested a more sensitive design (type-7), which can detect effects of practice with task B at the fore-test stage upon the efficacy of the intervening training of task A. Another control group-ii is added to the design-6, which is much like the experimental group except that it does not take the fore-test. However, a fore-test level can be assigned to the control group-ii as the average fore-test scores of the other two groups. Let us see: (a) for the experimental group, the pretest post-test differences is the joint effect of the fore-test practice of task B and practice of task A; (b) for the control group-i, these differences refer to the effect of fore-test practice at B upon final performance at B; and (c) for the control group-ii, differences between post-test scores at B and average foretest scores at B of the other two groups, is the exclusive effect of intervening training at A. Now, if the extent of alteration that has occurred in the experimental condition does not measure up to the total amount of change for the two control conditions (a does not equal b plus c), then the fore-test practice at B may have depressed the effects of intervening training at A leading to reduced estimates of transfer at B.

These methodological refinements are undeniably rather complicated, but almost everything about human behaviour is full of complexity. Although we are not constrained to use sound methodologies when time and resources are limited, we should be ready to recognise these methodological problems in our experiments and estimate their consequences.

Transfer formulas

Several transfer formulas can be used in order to measure the amount and direction (positive or negative) of transfer. Hammerton (1967) found more than 100 different formulas for transfer measures which he assigned into two broad categories (see figure 2.1): those which measure saving of training time or trials (savings measures); and those which deal with initial performance of subjects immediately after transfer (first-shot measures). The choice of a particular formula is important as each answers different questions.
Figure 2.1. Hypothetical learning curves of two groups, indicating potential transfer measures.
Savings formulas measure the saving of training trials in the performance of the transfer task following practice of the original task, and have the form:

\[ r = \frac{c-e}{c} \]

where \( c \) is the number of trials needed by the control group to reach a stable performance, and \( e \) is the number of transfer trials needed by the experimental group to do so.

First-shot measures deal with initial performance of subjects immediately after transfer e.g. correct responses or errors or time to meet the criterion, and answer three different questions. The first question is internal to a particular experimental group and asks: 'Given a certain amount of learning with the original task, how much of it will be retained on the first trial with the transfer task?' The answer is given by:

\[ x = \frac{O-E}{O-L} \]

where \( O \) is the mean performance on the first trial on the original task, \( L \) that on the last, and \( E \) that on the first transfer trial of the experimental group.

It is also useful to compare experimental and control groups in the performance of the transfer task, so the next question is: 'how does training retained on the first transfer trial (experimental group) compare with that gained by trainees who always performed the transfer task (control group)?'. This is answered by:

\[ y = \frac{C-E}{C-T} \]

where \( C \) is the mean first trial performance of the control group, \( E \) that of the experimental one, and \( T \) the stable performance of the control group. In cases where there is only one trial on the transfer task, \( T \) equals zero.

We can also compare the differences between experimental and control groups on the transfer task with the maximum amount of improvement possible. Gagne et al. (1948) have proposed the following formula:

\[ z = \frac{C-E}{C-H} \]

where \( H \) stands for the total possible score on the transfer task, presumably as it can be indicated by the performance of a human expert.

First-shot measures, as the name implies, are important where performance at the transfer task is of great concern even from the first trial. It is worth pointing out again, that the choice of a transfer formula will depend upon the type of questions being asked.
SPECIFIC TRANSFER

Transfer effects are named as *specific* if they can be referred to determinate similarity relationships between the elements of two or more succeeding tasks. A number of studies have shown that similarity between the original and transfer tasks is a major factor influencing the degree of transfer of learning. In general, the greater the degree of similarity between two tasks the greater the amount of positive transfer obtained. In real-life activities, however, two activities may be similar in some parts and dissimilar in others i.e. cutting of wood and cutting of stones. The decision to call them similar is often likely to be arbitrary. In the laboratory, we are on surer grounds and can manipulate common elements between two tasks more conveniently, so that the amount and direction of transfer be very precisely determined. Early transfer studies stemming from the *identical elements* approach, have been concerned with transfer of lists of paired-associates and simple perceptual-motor tasks which have clearly identifiable stimuli and well-defined responses.

Tasks which may be analysed into stimulus-response components may also vary along dimensions of either stimulus or response similarity. In general, similarity has been defined in two ways: (i) scales of similarity have been constructed based upon the judgement of subjects, including similarity of verbal material (Haagen, 1949) and similarity of perceptual material (Gibson, 1941); and (ii) similarity has been defined as variation along some known physical dimension such as size or intensity. In order to demonstrate any relation between similarity and transfer, it is always necessary to have some measures of similarity that are independent of the measure of transfer. Early transfer studies have used a variety of similarity measures and their findings, to some extent, depend upon their particular measure of similarity.

Transfer and similarity of stimulus-response pairs

Osgood (1949) presented a model of transfer based upon the effects of stimulus and response similarity. Osgood reviewed the existing literature and made three generalisations based upon experimental evidence. Many of the subsequent transfer studies can also be assigned into the three transfer paradigms summarised in table 2.2.
Table 2.2.  
Transfer of Training Paradigms, (Osgood 1949).

<table>
<thead>
<tr>
<th>Paradigm</th>
<th>Original task</th>
<th>Transfer task</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$S_0 - R_0$</td>
<td>$S_1 - R_0$</td>
</tr>
<tr>
<td>B</td>
<td>$S_0 - R_0$</td>
<td>$S_0 - R_1$</td>
</tr>
<tr>
<td>C</td>
<td>$S_0 - R_0$</td>
<td>$S_1 - R_1$</td>
</tr>
</tbody>
</table>

Paradigm A describes the situation in which the stimuli in the transfer task are varied and the responses are the same ones as in the original task. Studies on paired-associate learning (Yum, 1931; McKinney, 1933; Hamilton, 1943) and on perceptual-motor tasks (Duncan, 1958) have shown that positive transfer is always observed for paradigm A which increases with increasing the stimulus similarity.

Paradigm B describes the situation in which the responses in the transfer task are varied but the stimuli are kept the same. Osgood indicated that negative transfer is obtained which decreases as the similarity between the responses increases. This is generally true in cases of perceptual-motor tasks, in which antagonistic responses are often introduced in the transfer task i.e. when a person has to push a lever when a green light goes on whereas in the original task he had to pull the lever. However in paired-associate learning, responses may be dissimilar but rarely antagonistic and thus, negative transfer is rarely observed. In fact, a study by Underwood (1961) has indicated evidence for positive transfer when subjects learned to make new responses to the same stimuli. Thus, paradigm B may have different implications for verbal learning and perceptual-motor tasks.

Finally, paradigm C describes the situation in which both stimuli and responses are varied in some degree of similarity. The direction of transfer will depend upon the degree of stimuli and responses similarity. In general, this is considered to be a case of zero transfer. A study by Gibson (1941) has shown that if the responses in the transfer task are quite different from those in the
original, then the greater the degree of stimuli similarity the less the amount of positive transfer.

Some limitations of the task similarity model of transfer

The Osgood model appears to be based partly on the mechanisms of stimulus generalisation that may underlie transfer effects. If two tasks present similar stimuli and require the same responses, what is learned in relation to the stimuli presented with one task will generalise to the related stimuli of the transfer task. On the other hand, when responses learned in one task interfere with responses on the second task, negative transfer is observed. However, this prediction was not completely true in verbal learning as the study by Underwood (1961) indicated.

It is quite difficult to use Osgood’s model of transfer for predictive purposes because we cannot know a priori where we are on the dimension of similarity. Unless we can measure similarity in some adequate fashion, this model has limited utility in predicting transfer effects. Osgood’s model encounters additional difficulties, when we are faced with real-life activities which are not easily amenable to an analysis of clearly identifiable stimuli and responses.

In general, Osgood’s model suits a view of learning in which learned behaviour is seen as a series of conditioned reflexes (a stimulus followed by an automatic response). It does not take into account cognitive mechanisms i.e. language which mediate stimulus and response associations. Other variables influencing transfer such as amount of learning and learning-to-learn are not addressed.

Finally, stimulus generalisation is not the only mechanism which accounts for transfer. In later sections, we will see other conceptual models of transfer which were suggested to explain transfer.

NONSPECIFIC TRANSFER

The learning and transfer that have been considered up to this point have involved quite simple processes. Such processes manifest themselves in the learning of some process control operations with which the trainee interfaces
the system such as actuating pumps or adjusting valves. If we construe these interfacing operations as being analysed into clearly identifiable stimulus-response pairs, the Osgood's transfer model might be useful in predicting transfer. For instance, if trainees have to respond with the operation 'CTRL-O-P-1' to a stimulus 'open pump-1', then positive transfer may arise when they have to respond with a similar operation 'CTRL-O-P-2' to another stimulus 'open pump-2'; whilst negative transfer may arise when they have to respond with 'P-2-O' to the second stimulus.

However, much of what is learned in process control tasks involves not only the acquisition of simple habits or interfacing operations but also the acquisition of more complex operations such as 'stabilising levels in vessels', 'building up temperature profiles' and so forth, in which transfer is a function of gross similarity relationships that cannot easily be analysed in any explicit manner. These additional transfer phenomena are also a function of similarity between tasks, but because similarity cannot easily be specified in terms of clearly identifiable components it is commonly called nonspecific transfer. These transfer phenomena include transfer of concepts and principles, transfer of strategies, learning-to-learn, warm-up and bilateral transfer. An analysis of the transfer of concepts and principles will illustrate this point.

Transfer of concepts and principles

Transfer of principles and concepts is an area which has only recently been investigated. In school education, there is a long standing requirement that students be able to apply concepts and principles, commonly found in textbooks of physics and chemistry, outside the original contexts in which they were learned. In a similar vein, training of apprentices should enable them to recognise different situations which are governed by the same principle of physics or chemistry.

Travers (1977) cites an example of learning the Archimedes' principle of buoyancy, through a demonstration involving the change in the weight of a piece of lead when it is immersed in water. Trainees' understanding of the principle may be tested by transferring them to a situation in which they have to explain why smoke rises in a chimney. Some positive transfer will occur, but not because of any similarity between task elements involved or any overt
responses. What the trainee must recognise is that a solid body immersed in water has an upward force exerted on it by the water, and that a body of hot gas also has an upward force exerted on it by the surrounding air. Both situations have to be encoded as situations involving an upward thrust upon a body exerted by a surrounding medium and, thus, as utilising the principle of buoyancy. The application of a principle to different situations demands that the situations have some similarity, but this can hardly be interpreted in terms of a simple concept of stimulus similarity. Positive transfer occurs, when trainees can abstract certain similarities of both situations and code information in the two situations in the same way.

Learning of concepts and principles suits a view of learning that goes beyond the traditional behaviouristic one, in which behaviour was seen as a series of conditioned responses. In order for the trainees to be able to reason at an abstract level, learning behaviour entails the presence of some cognitive processes mediating stimuli and responses. One form of cognitive process is what has usually been called schemata - that is, knowledge structures stored in human memory which are constantly revised as a function of the acquisition of new material. This notion of cognitive structures was first identified by Barlett (1932) and has recently been expanded by Ausubel (1963) in his work of advanced organisers. According to this theory, learning of new material is substantially facilitated when trainees possess some form of knowledge structure within which they can organise new learning. Research stemming from Bransford and McCarrell (1974), Franks (1974) and Royer (1979) have also explored different ways in which children could develop new concepts and principles and transfer them to new situations. These authors have tried to examine the effect of different forms of knowledge structures such as abstract structures versus concept exemplars upon transfer in new situations.

Other studies have been more concerned with types of training methods which enable trainees to classify situations as belonging to different classes or knowledge structures, rather than examining the precise form of these classes. A study by Duncan (1974) has described a task in which operators had to classify valves into different classes such as 'inlet', 'outlet', 'drain', 'isolating' and 'by-passing' valves, according to the position of valves in lines about pumps, automatic controllers and sensing devices. Duncan (1974) found that trainees who practised this task in a variety of relevant contexts transferred better than those who practised the task in the same context. Thus, variety of original learning assisted trainees to transfer their concepts to new situations.
However, it is not always possible for the trainees to recognise similar principles under different situations, because similarity relationships are not easily analysed into stimulus-response associations. This is why trainees may need particular types of training to enable them to understand gross similarity relationships. A study by Fotheringhame (1984) failed to promote transfer from the use of a micrometer in a motor vehicle serving context to the use of a height gauge in a general engineering context, although both situations were governed by similar principles. Annett and Sparrow (1985) who reviewed that study argued that training was too closely bound to the specifics of using a micrometer rather than teaching the general principles of measurement. We can see, therefore, that concepts and principles can transfer to new situations provided that training enables learners to recognise certain abstract features common to the two situations.

So far, we have considered transfer to situations which involve similar concepts and principles. It is also possible to observe transfer to situations which entail different concepts and principles when these refer to similar schemata or cognitive data structures. This is the case of learning a principle by drawing an analogy with other principles of different domains. In a study by Gentner and Gentner (1983), subjects learned concepts and laws of electricity such as electric current, voltage, resistors etc., by drawing analogies to concepts and laws of hydraulics models such as water flow, pressure and obstructions respectively. In other studies by Royer and Cable (1975) and Royer and Perkins (1977), students had to learn principles of heat flow in metals and transfer to principles of electric current by making reference to a model of molecular structure of metals. What is transferred in this situation, is a particular form of data structure or model of metals which explains flows of electricity and heat. Trainees may have to reason in higher levels of abstraction and understand that principles of different domains may have common data structures. Holyoak (1984a) suggested that these schemata or data structures can be construed as networks of objects which have certain attributes and causal relationships. Learning these schemata by analogy is not always easy, and in many cases may harm generalisations or transfer to new situations because it entails an ability to identify objects, attributes, and causal relationships common to principles of different domains (Holyoak 1984b). Learning by analogy can expand to include learning problem solving skills, in addition to learning schemata but this issue will be further elaborated in the discussion of models of skill acquisition and transfer in chapter 5.
In summary then, a number of recent studies have provided some evidence of transfer of concepts, principles and larger cognitive structures to novel situations. These studies, however, have not controlled for specific transfer or other forms of nonspecific transfer and they have not employed any rigorous transfer designs.

Transfer of strategies

Although learning of concepts and principles is very important in operating a process plant, efficient performance requires additional abilities in making optimal use of these concepts and principles in actual plant operation. Mastery of theories underlying plant operations is quite distinct from mastery of strategies in assigning priorities and in sequencing theoretical concepts and principles for different kinds of operations. On many occasions, it is even possible for effective and well-practised strategies not to make reference to underlying principles originally used to develop such strategies. Studies of human expert behaviour in electronic trouble-shooting (i.e. Williams and Whitemore, 1959) have shown that experts use effective trouble-shooting strategies without recalling the theoretical principles underlying their strategies.

Transfer of strategies to novel situations is an issue which has recently been addressed by studies in process control (Shepherd et al., 1977; Marshall et al., 1981; Rouse and Morris, 1981; Reiersen, 1985; Patrick and Haines, 1988; Patrick and Munley, 1988). These studies have developed effective methods for training diagnostic skills for plant failures which had not previously been encountered by human operators. Training methods included explicitly stated heuristics (Shepherd et al., 1977; Marshall et al., 1981) or learning of plant-theory to the extent that trainees developed their own diagnostic procedures (Reiersen, 1985; Patrick and Haines, 1988).

These studies, however, have been restricted to the transfer of diagnostic strategies either to novel process failures in the same plant or to highly similar plants (Patrick and Haines, 1988); we do not know the extent that these strategies can transfer to other process control operations such as start-up or recovery of the process and so forth. In addition, transfer of strategies could well be accompanied by transfer of common task elements and theoretical principles, and it becomes quite difficult to estimate the relevant contribution of each separate component to the overall transfer. Nevertheless, strategies can
transfer to novel situations provided that training guides learners how to perceive a known strategy as being relevant to the new situation.

Learning to learn.

It is commonly observed that individuals improve in their ability to learn new tasks when they have practised a series of related tasks. This progressive improvement in performance is a form of transfer known as learning to learn. The similarity relationships involved in learning to learn are general approaches or modes of attack, becoming familiar with the situation, and learning related classes of materials.

Among the earlier studies of learning to learn, is a study by Ward (1937) in which subjects required to learn successive lists of nonsense syllables, one list a day. Subjects' performance was rapidly improved in successive lists, whilst after six lists their improvement became more gradual. It was clear that subjects learned how to learn this type of material even though it consisted of meaningless syllables. A psychological mechanism which is often cited to account for learning to learn phenomena, is the acquisition of a learning set for a particular class of problems through extensive practice on related problems (Harlow, 1959). Harlow has also pointed out, that an important factor in establishing a reliable learning set is the extensive practice in the early trials; as a learning set becomes more securely developed, relatively few trials are necessary on more complex problems. The importance of providing extensive practice on a series of related problems for the development of complex skills, was also recognised by early studies in programmed instruction (Skinner, 1954).

Learning-set theory, although having important implications for educational practices, has not provided us with adequate explanations about the specific components of a learning set. We do not know what precise types of knowledge and skills make up a learning set and neither we know the optimal learning conditions for teaching each particular component of the set.

More recent studies in the context of problem solving skills, have thrown more light into what is usually referred to as learning-to-learn skills. Although these studies have not addressed the issue of transfer in any explicit fashion, they have contributed a lot to our understanding of learning to learn. Studies of reasoning styles of experts and novices in such domains as physics (Larkin et al., 1980) and geometry (Anderson, 1983) have shown that experts tend to reason
forwards whereas novices tend to reason backwards for different problems within the same domain. The backward chaining approach of the novices reflects their reliance upon domain independent methods such as means-ends analysis, where people start with a set of 'givens' and work backward to the goal statement. With the increase of expertise, people learn which of the many alternative forward inferences are required for the final solution (Anderson, 1985).

In other problem domains, however, experts seem to change their reasoning style to the particularities of that domain. In computer programming, for instance, both novices and experts adopt backward chaining strategies because the 'givens' of a programming language are not richly predictive of the solution to the goal statement. Anderson et al. (1984) and Jeffries et al. (1981) have found that novices adopt a depth-first strategy, whereas experts adopt a breadth-first strategy which enables them to detect the dependencies among sub-goals at each design level before proceeding to the next.

Learning to learn is a complex phenomenon and expands beyond the acquisition of a learning set or appropriate reasoning styles. It also includes the actual control of the whole learning effort by the learner himself. Studies by Smith (1982), Knowles (1975) and Downs and Perry (1982) have outlined a number of learning activities taken by the learner, which constitute techniques how to learn new material. Activities taken during learning can include:

(i) Decomposing the overall learning problem into a set of manageable subordinate goals;
(ii) Developing methods for achieving these goals in a manner that cognitive load is kept to a minimum, and deciding upon performance criteria for the completion of each goal; and,
(iii) Evaluating the effectiveness of utilised methods and strategies as well as revising them for future use.

The different training methods suggested for enabling learners to take control of their learning go beyond the scope of this section. It is encouraging, however, to know that what can transfer to a new situation might be a generic ability of learning how to learn new material.
Warm-up

Warm-up is a more transitory or short-lived effect than learning to learn, and results in attentive or motor readiness on the part of the subject. Another characteristic of warm-up is implied in the fact that it accumulates only so long as the warm-up exercise lasts. Thereafter, it starts dissipating quickly. A study by Hamilton (1950) has shown a transitory facilitation in the learning of paired-associate lists of meaningful words, when these were practised soon after the initial list. After a sixty minute interval the facilitating effects were smaller and rather constant. Similar results were obtained by Thune (1950), who was able to isolate warm-up and learning to learn effects in a single experiment.

Bilateral transfer of motor skill learning

Transfer from a member on one side of the body to its opposite is often called bilateral transfer. In ball-tossing, for instance, skills of manipulating the ball, the task of flicking it to the correct angle and height, the right balancing of body weight and musculature are transferable from the preferred to the nonpreferred member of the body, although with considerably less skill.

CONDITIONS OF PRACTICE INFLUENCING TRANSFER

The degree of specific and nonspecific transfer will ultimately depend upon the conditions and the extent to which the original task has been practised. Conditions of practice may include: (i) time interval elapsing between tasks; (ii) degree of original-task learning; (iii) variety of previous tasks; and (iv) relative difficulty of the original task. We will discuss each of these conditions in greater detail below, because these may influence the degree and direction of transfer.

Time interval between tasks

In the late 1930s, Bunch and his associates reported a series of experiments demonstrating that transfer effects remained fairly constant over periods as
long as 90 days, whilst retention of the original task declined \(\text{Bunch, 1936; Bunch and McCraven, 1938; Bunch and Lang, 1939}\). More recent studies by Ellis and his colleagues have suggested a two-process model of transfer in order to explain conditions under which transfer remains invariant over time. They held that the response learning component is not stable over time, in contrast to the following associative 'hook up' component which is stable over time. Associative 'hook up' may be supposed to include some form of scanning and choosing from a limited set of linking mechanism, and it might be relatively more stable over time because it may be practised to a greater extent than the individual responses. In this way, transfer of paradigm \((S_0\cdot R_0, S_1\cdot R_1)\) remains stable over time because there is no new response learning \(\text{Ellis and Burnstein, 1960}\); in contrast, transfer of paradigm \((S_0\cdot R_0, S_0\cdot R_1)\) declines over time because it entails new response learning \(\text{Ellis and Hunter, 1960}\).

A more recent study by Duncan (1971) has offered more insights into the temporal course of transfer. In that study, subjects learned a fault location task with the help of a decision tree routine, and they transferred to a similar task after an interval of either 6, 58 or 182 days. Duncan (1971) showed that transfer was fairly stable over time, whereas retention declined only for the group of subjects who could not generalise beyond the specific search sequence. Subjects who were able to develop more general rules e.g. a 'half-split' rule retained the original task fairly well.

This finding is consistent with the conclusion drawn by McGeoch and Irion (1952) from studies of less complex tasks, namely, that effects of learning which are stable over time consist of general factors such as modes of attack. In general then, the findings of the above studies reveal that transfer of training remains fairly constant over time, as performance on the transfer task does not depend upon memory for specific items in the original task.

**Degree of original learning**

Many studies have confirmed an old rule of thumb which says that, positive transfer increases with increasing practice on the original task. Mandler (1962) has summarised the research on this variable and indicated that there is a U-shaped function relating amount of transfer and degree of original learning. That is, with small amounts of practice there is frequently a negative transfer
effect, then a zero transfer with more practice, and increasing positive transfer with even more practice.

However, another study by Postman (1962) has only partially confirmed this generalisation. Postman (1962) found negative transfer for several transfer paradigms when compared with the control condition \((S_0-R_0, S_1-R_1)\). The amount of negative transfer was greater for the \((S_0-R_0, S_0-R_1)\) condition and least for the \((S_0-R_0, S_1-R_0)\) condition. With the increase of practice, negative transfer began to decrease but it did not return to positive transfer. Perhaps, if additional practice had been given the usual U-shaped function may have been found again.

In summary then, the findings suggest that the greatest amount of negative transfer is likely to occur after relatively little practice on the original task. With extensive practice on the original task one runs much less risk of negative transfer. This is consistent with the argument made by Harlow (1959), namely, that considerable practice should be given on early problems of a series in order to maximise transfer in subsequent learning.

**Variety of original learning**

Practice with a variety of related tasks as opposed to extensive practice with a single task is an important variable in influencing transfer. It will be recalled that studies of learning to learn (Harlow, 1959) indicated that practice of a series of related problems leads to successive improvement in performance; however, these studies do not separate the effects of amount of practice from those of variety of practice.

It was only until recently that a study by C. P. Duncan (1958) illustrated the separate effects of sheer amount of practice from those of variety of practice on transfer. That study showed that transfer was also increased as a direct function of increased variety of original learning. The increased positive transfer due to task variety was most prominent with two types of original tasks, whereas it dropped when going to five or ten different tasks. C. P. Duncan (1958) argued that variety of original learning could be an enabling learning condition for developing a learning set or even learning to learn techniques. It will be recalled from previous sections, that K. D. Duncan (1974) has also found that variety of original learning is a useful method for
teaching various concepts in process control tasks such as 'inlet', 'outlet', 'by-passing' valves and so forth.

It appears then, that certain forms of practice of original learning such as variety of tasks may be required for particular types of nonspecific transfer such as transfer of principles and learning to learn.

Transfer and task difficulty

Several transfer studies have addressed themselves the question: 'Does preliminary training on an easy or a more difficult task result in greater transfer?'. Unfortunately, generalisations about the role of task difficulty in transfer are complex, since it is not easy to know what constitutes comparable levels of difficulty with different tasks.

Studies on the task difficulty and transfer seem to be rather inconclusive. For instance, some studies of tracking tasks (Baker et al., 1950; Goldstein and Newton, 1962) which manipulated task difficulty by varying gear ratio and target speed, favoured difficult-to-easy transfer; other studies by Lincoln and Smith (1951) favoured easy-to-difficult transfer, whilst Lordahl and Archer (1958) found that when the original training was either easier or more difficult transfer was negative.

Holding (1965) has cautioned that it is only when we wish to perform a series of tasks, rather than a single task, that the order in which these tasks are learned is of practical importance. If we are concerned with mastery of a single task, we should be better off when practising the particular task rather than easier or more difficult versions of the task. In earlier studies, Holding (1962) have explored the transfer effects of two different task characteristics. The first characteristic that of inclusion, favours difficult-to-easy transfer, since the difficult task includes the easy one. The second characteristic that of performance standards, has an opposing influence on transfer and favours easy-to-difficult transfer. This is justifiable in that, on the difficult version, looser standards of performance become customary and carrying these over to the easier task will result in poor performance.

A tentative conclusion which could be drawn here is that, transfer from difficult tasks will give wider experience and produce greater amount of
learning. while transfer from easier tasks will produce more accurate learning. However, what will happen in detail will depend upon what constitutes 'difficulty' for a particular study.

EARLY THEORETICAL DEVELOPMENTS IN TRANSFER

A problem in transfer studies has been the lack of systematic theory that would serve both to organise diverse empirical findings and to predict new relationships. Although a number of conceptual models have been suggested to account for specific transfer, we still lack adequate models to understand the nature of transfer of concepts, strategies and learning to learn techniques. There is a need to integrate suggested mechanisms for both specific and nonspecific transfer within the framework of a systematic theory. In this section we will discuss only the early theoretical models of transfer which will be integrated within a general model of transfer in chapter 5. Early models of transfer can be assigned into one of five areas. These areas include: (i) stimulus generalisation; (ii) two stage-theory of learning; (iii) stimulus predifferentiation; (iv) transposition; and (v) learning set theory.

It will be recalled that stimulus generalisation is a psychological mechanism underlying the Osgood model of transfer. However, this model can not explain the finding by Underwood (1961) that paradigm B (in table 2.2) does not result in negative transfer in tasks which involve verbal learning. The two stage-theory of learning advocated by Ellis and Burnstein (1960), was proposed to account for paradigm B and most types of transfer in verbal paired-associate learning. This model has already been considered in the temporal course of transfer, so it will not be discussed further.

A third model, that of stimulus predifferentiation was developed to account for the influence of preliminary experience with the stimulus aspect of a task on transfer of learning. In the pretraining task, subjects label various aspects of stimuli so that stimuli become predifferentiated, and this facilitates subsequent transfer to a task which involves the same stimuli associated to qualitatively different responses. Mechanisms involved in this phenomenon include 'enriching the stimuli with cues' (Goss, 1955), 'distinctiveness of stimuli' (Gibson and Gibson, 1955), and 'attention to cues' (Robinson, 1955).
Finally, *transposition* is a mechanism which accounts for subjects' tendencies to respond to relations among stimuli rather than absolute features of the stimuli, in discrimination learning (Spence, 1956). All models considered so far are concerned with specific transfer effects; the only model which concerns nonspecific transfer is the *learning set theory* (Harlow, 1959), which was discussed in the learning to learn techniques.

Unfortunately, these conceptual models are of limited utility in developing a systematic model of transfer for making predictions about transfer of learning. In chapter 5, a model of transfer is proposed to serve as a basis for developing training methods for optimising transfer.

**DISCUSSION**

Transfer of learning between two tasks will be observed, when an individual adopts similar psychological mechanisms or cognitive processes to perform these tasks. Some of these mechanisms have already been discussed in the early theoretical developments in transfer. Other mechanisms may include: reasoning at abstract level, activation of cognitive data structures (see section in transfer of concepts and principles), development of a learning set, management of memory and attention in learning to learn and so forth.

The literature review of transfer studies has suggested that, in order to predict whether two tasks may bring into play similar cognitive processes, we need to consider ways in which tasks are different or similar to each other. In general, we discussed two forms of transfer, namely, specific and nonspecific similarity relationships. When two tasks share identical stimulus-response associations or similar concepts and principles or similar strategies, there is a basis to predict that an individual may adopt similar cognitive mechanisms. In addition, when tasks belong to the same class of problems, any acquired learning to learn techniques may facilitate subsequent learning.

However, it is not always possible for the trainee to recognise nonspecific similarity relationships, and appropriate conditions of practice have to be provided e.g. time interval between practice trials, degree of original learning, and variety of learning.
Finally, a number of transfer studies have been carried out in the context of text-editing skills (Pison et al., 1986; Ziegler et al., 1987; Karat et al., 1986; Pollock, 1988), but because most of them utilise modern models of skill acquisition in terms of production rules, they will be dealt with in chapter 5. In brief, production rules are like stimulus-response pairs and these models predict that transfer of learning occurs when two tasks share identical production rules. Modelling learning and transfer in terms of production rules is a very popular approach nowadays, however, the assumptions upon which these are based may be valid only for procedural skills such as text-editing, and not for complex and flexible skills such as process control skills.

CONCLUDING REMARKS IN A PROPOSED APPROACH TO TRANSFER OF PROCESS CONTROL SKILLS

The application contexts of most transfer studies concerned paired-associate tasks, relatively simple perceptual-motor tasks and text-editing skills. Process control tasks, however, are very complex cognitive tasks and it is quite difficult to examine what types of psychological mechanisms and combinations of them are brought into play, by merely viewing at specific and nonspecific task relationships. In addition, different operators may perform the same task in different ways which makes transfer predictions even more difficult. A number of psychological models in process control exist which point out the flexibility in the performance of process control tasks. These models include: manual control models (Crossman and Cooke, 1962); decision making models (Bainbridge, 1978; Beishon, 1969) and multiple modelling approaches (Rasmussen, 1976).

In starting-up a chemical plant, for instance, the human operator may take a variety of actions, ranging from fairly simple ones such as 'actuating pumps' and 'adjusting valves' to more complex ones such as 'stabilising levels' and 'building temperature profiles'. Transfer of the simple operations can be examined by utilising the Osgood model of transfer, but we have no basis to predict transfer of the more complex ones. Although a certain amount of transfer of concepts and principles may be observed between two tasks, the actual performance on the tasks will depend upon various skills such as analysing the tasks into sub-goals, applying well-practised methods of operation
and so forth. In order to compare different types of performance entailed in different tasks, a method of task analysis is required.

The approach which is adopted in this thesis consists of two stages. In the first stage a method of task analysis is developed in order to redescribe tasks into a set of subordinate operations, and plans for selecting and organising operations into superordinate ones. A taxonomy of plans and operations is also developed in order to assist the analyst identify task elements that have similar patterns of plans and operations. Task elements similar in form may prompt an individual to adopt similar psychological mechanisms, and this can be used as a basis for predicting transfer effects.

In cases where the same task element entails different behaviours, we can further constrain the behaviour of trainees by developing training methods to encourage them to adopt the most efficient and transferable behaviours. This constitutes the second stage of the approach of this thesis, where a model of learning is suggested to serve as a basis for developing training methods. According to this model, learners are considered to possess a response repertoire which consists of a number of knowledge items such as those identified in the literature review e.g. concepts and principles, task elements, strategies etc. The trainee's repertoire is used as a model for predicting transfer effects. Various psychological mechanisms examined by previous transfer studies are integrated within the proposed model of learning. In the following chapter 3, a method of task analysis will be discussed which can be used as a framework for utilising a model of learning and make transfer predictions.
CHAPTER 3

TASK ANALYSIS AS A FRAMEWORK FOR CONDUCTING TRANSFER STUDIES IN PROCESS CONTROL TASKS

SUMMARY

Any study of transfer of training will have to specify the size of the behavioural units at which transfer is investigated. For instance, previous transfer studies have mainly been concerned with low-level units e.g. primitive operations and general concepts, for their particular application domain. More complex tasks, however, such as process control tasks require additional examination of high-level units e.g. plans and intermediate goals which need to be mastered by operators. The purpose of this chapter, therefore, is to develop a method of task analysis in order to identify subordinate task elements and to examine ways in which these compile into the overall process control task. The proposed task analysis methodology will be used as a framework for conducting transfer studies, exploiting the various models of transfer which have been reviewed.

INTRODUCTION

Process control tasks are complex cognitive tasks and it becomes increasingly difficult to identify whether specific or nonspecific transfer or even a combination of both operate in a particular situation. Although, it is conceivable that transfer may be observed due to either common interfacing operations e.g. 'opening pumps', 'adjusting valves' etc., or common concepts and principles, we have no basis to estimate the degree to which these will enhance performance on the transfer task. In process control tasks, the skill in 'running a plant' does not rest with mastering a great variety of interfacing operations and understanding various principles but mainly with planning how to select and sequence these in appropriate orders. Planning behaviour may also manifest itself at many levels of detail; a view often endorsed in experimental psychology.
We need, therefore, a method of task description which can show aspects of this planning behaviour in process control tasks, so that we can examine how different types of specific and nonspecific transfer impinge upon tasks. A method of task description which has extensively been applied in the analysis of process control tasks is Hierarchical Task Analysis (or HTA, in short). Studies by Shepherd et al. (1977), Marshal et al. (1981), and Patrick and Haines (1988) have used HTA in order to derive effective diagnostic strategies which were subsequently trained either in the form of explicit 'heuristics' or by allowing trainees to evolve them through a good knowledge of plant-theory.

In this chapter, we will discuss how HTA can be used as a basis, mainly, for making predictions about specific transfer of process control operations. Its suitability as a framework within which to consider various models of nonspecific transfer will also be addressed.

**TYPE OF DESCRIPTIVE BASE**

A plethora of different methods of analysing tasks have been suggested in the literature. One means of classifying these methods is by the descriptive variables employed. A review by Patrick (1980) has distinguished between types of analysis which used task-oriented descriptive variables and those which used person-oriented ones. A similar distinction had been made by Miller (1962a) between task description and task analysis. Task description is concerned with describing the goals of behaviour required to perform a task. On the other hand, task analysis or person-oriented descriptions attempt to specify the psychological demands experienced by the operator while performing the task. The former describe the terminal behaviour required of an operator, whilst the latter describes the course of behaviour.

Many forms of task description mainly comprise of a list of things the operator has to do without being able to describe the way in which these different things are planned, e.g. R. M. Miller's (1962b) description of the task of 'adjusting a radar receiver'. This deficiency is a particular problem in describing process control tasks in which the skill rest with planning when and how to do these things. Other writers have adopted algorithms to describe this sort of complexity e.g. Singleton (1974) and Lewis et al. (1967), but this method of deriving task descriptions still requires considerable development. The
method of task description which is adopted in this thesis, that is, HTA seems to be especially powerful in describing tasks with a considerable planning component because of its structure in terms of plans and subordinate operations.

On the other hand, task analysis methods which attempt to prescribe the abilities or cognitive processes demanded in a task are particularly attractive, because they provide a basis to examine the conditions under which these abilities or processes may transfer to other situations. Patrick (1980), who looked at various task analyses appropriate to the analysis of transfer of skills, has distinguished two different approaches. The first one is the information processing approach which describes a variety of processes intervening between input and output which affect performance. R. M. Miller (1953, 1962a, 1962b) was among the first to codify these processes as scanning, search and detection of cues, interpretation, short and long term retention, and decision making and problem solving. Several other schemes proposed by other authors (Fitts, 1962; Gilbert, 1962; Mencher, 1965) are variations of this basic input-processing-output model. Gagne (1965a, 1965b) has proposed a classification scheme of behaviours, each category requiring different learning conditions. Some of Gagne's categories can be thought of as combinations of cue-response units, rather than as processes intervening between cues and responses e.g. the 'chain' category in which cue-response units are combined in sequence or the 'concept' category in which cue-response units having the same responses are combined.

The second class of task analysis methods is the abilities approach which assumes that people possess relatively enduring traits and abilities which can transfer to various situations. The Position Analysis Questionnaire of McCormick et al. (1969) and the factor analytic approach of Fleishman (1962, 1978) in identifying various abilities, belong to this class of task analysis methods.

The problem with the information processing and abilities approaches is that it is difficult to specify the level of description required and consequently the number of categories which are useful for mastering a particular task. In addition, the time required and methodological complexities of making a link between categories and task-oriented data is a major drawback at present.

This thesis starts with an existing version of task description (namely, HTA) and proposes a way of extending it, so that it provides a framework within which to consider other person-oriented approaches and examine transferability of skills.
HIERARCHICAL TASK ANALYSIS FOR PROCESS CONTROL TASKS

Hierarchical Task Analysis (HTA, in short) is a method of task description which has been originated by Annett et al. (1971). HTA has extensively been applied mainly in the area of process control training by various researchers e.g. Duncan (1972, 1974, 1975), Duncan and Gray (1975), and Shepherd (1976, 1980, 1985). It has also been suggested for non-training solutions such as display design (Astley and Stammers, 1987), development of job-aids and re-allocation of functions (Shepherd, 1986).

The technique of HTA is, briefly, as follows. HTA commences by describing the job or task in terms of an operation - an instruction to achieve a goal, such as 'run plant' or 'operate distillation plant'. If the analyst decides that the operator cannot perform this operation to a desired standard and a performance solution - job-aids, straightforward training regimes, display modifications etc. - cannot be found, then he will attempt to further redescribe this operation into a set of subordinate operations and a plan which governs the conditions under which each of the subordinate operations is carried out. Each of these operations is then examined, and further redescription is attempted for those operations where the means to ensure competent performance are unclear. But sometimes, the analyst cannot see how to redescribe an operation properly so he must opt either for a less satisfactory plan or stop redescription and look harder for a performance solution which would be unacceptable at the first instance e.g. re-allocation of functions or simulation training. Shepherd (1985) has summarised the decisions taken by the analyst in a graphical form, which clearly demonstrates the continuous 'hypothesis generation' by the analyst for means of ensuring performance.

Operations are stated as the operator's goal in changing the system under control and achieving a new state. Thus, operations can be seen to comprise an action to achieve a goal and feedback to enable the operator to judge what, if anything, remains to be done. There are obvious comparisons between an operation in HTA and Miller, Gallanter and Pribrams TOTE unit (1960). In the TOTE unit, feedback about the current state of the system is compared with the goaled state, congruity between the two indicating completion of the goal, while incongruity signifies the need to operate, followed by another test of congruity.
The plan is an important component of HTA because it describes the cues the operator must attend, the way in which various activities should be sequenced, and the time when an operation has been completed. The notion of a 'plan' has the same meaning given by Miller, Gallanter and Pribram (1960). While Miller et al.'s ideas stimulated the thinking behind HTA there may be a danger in taking the comparison too far. It must be emphasised that they were discussing the structure of behaviour while HTA describes the structure of the tasks. HTA can show the complexity of planning behaviour entailed in a task, but it does not correspond to the organisation of behaviour.

A substantial benefit of a hierarchical description is that analysis can stop at a point which is seen to be appropriate by the analyst for designing training or any other means to promote competent operation. Annett et al. (1971) suggested that redescription can stop when the product of the likelihood of inadequate performance (P) and the cost of inadequate performance is acceptable to the person sponsoring the analysis. There are, however, certain practical difficulties in applying the \( P \times C \) rule e.g. \( P \) is subjectively estimated, since formal approaches such as Swain's THERP (1964) or Embrey's (1979) 'performance shaping factors' techniques could not be undertaken throughout the whole course of HTA. Nevertheless, the rule is useful because it emphasises the factors an analyst should consider when deciding redescription.

In addition to the flexibility in the levels of description, HTA provides the analyst with a powerful means of redescribing complex plans into a hierarchy of simpler plans, each governing fewer operations. A further benefit can be seen when the trainee can concentrate practice on rationally identified parts of the task, rather than try to master the complexities of the whole task from the outset. An excellent illustration of the way complex plans can be analysed and re-assembled from simpler plans is given by Shepherd and Duncan (1980). Finally, the hierarchy of plans lends itself to the development of a classification scheme of plans which is suggested in this chapter.

MODIFICATIONS TO HIERARCHICAL TASK ANALYSIS

Hierarchical Task Analysis is a methodology for identifying training needs or making suggestions of other ergonomic means to promote competent performance. It is conceivable that HTA can also be used for setting up
hypotheses about transfer of task elements, namely, operations and plans. It will be recalled that the only types of task elements considered so far by previous transfer studies were stimulus-response units. The possibility of identifying 'chunks' within a complex task, with similar organisations of plans and operations is a very attractive idea, because it can be used as a basis for setting hypotheses about transfer. An empirical question which is addressed in this thesis is that 'task elements similar in form may prompt an individual to adopt similar cognitive processes and transfer will be observed'. If transfer is not observed, the learning conditions under which these elements were originally acquired can be changed and further hypotheses can be put forward. The proposed version of HTA still maintains its character as a method of task description and provides a framework within which models of learning and information processing approaches can be used to explore transfer. The modifications and extensions to the existing version of HTA concern the stopping rule, hypothetical statements and categorisation of task elements.

(1) Stopping rule

Task description should stop at the point where the operator interfaces with the system, for example, when pumps are switched on or valves are opened. This replaces the earlier \( P \times C \) stopping rule which requires redescription only as far as is necessary, as indicated by the product of the probability and cost of inadequate performance. This is necessary, in order to create configurations of operations and plans even for operations which are within the operator's competence, and which were not redescribed further. Redescription of these operations may proceed up to the point at which the operator interfaces with the system. The analyst should ask the operator to state an explicit plan of how he goes about to perform these low level operations and subsequently keep a record of it. In this way, the analyst will be able to see the extent that two operations entail similar or different plan structures, at any level of description. If we assume that conflicting plan structures can lead to interfering behaviours, and thus to negative transfer, then we can either modify these operations or identify training conditions which minimise any interference e.g. extensive practice of these operations separately (Shepherd, 1989).
(ii) Hypothetical descriptions

Earlier versions of HTA emphasised the need to describe tasks categorically, avoiding hypothetical statements (that is, statements about psychological processes). This rule of categorical description is important because many different forms of operator behaviour are able to achieve a required goal; furthermore, the behaviour which supports some performance may be very obscure. The analyst must keep an open mind by observing the rule of categorical description. However, once training has been selected as a solution we need not be constrained by what the operators actually do, but are free to impose any form of behaviour that they could follow effectively (Rasmussen, 1981). Tasks such as 'control panel diagnosis', for example, could not be described any further without the analyst assuming a hypothetical psychological model of the diagnostic process, e.g. a 'hypothesis-generation' or 'heuristic' or 'pattern-recognition' model. For training design, therefore, task descriptions need not be categorical, but can be extended to describe behaviour that operators may be encouraged to follow.

Hypothetical descriptions of performance is the link of HTA to any type of model of performance or learning; the model of learning described in chapter 5 is useful in setting learning conditions which optimise transfer.

(iii) Categorisation of task elements

Previous accounts of HTA emphasised precision in the statements of plans, but did not constrain the form in which they should be represented. In order to make predictions about transferability of similar task elements, we need to define similarity in terms of a number of categories of task elements. Three sorts of task-element classification are proposed: interfacing operations, plans, and intermediate goals (or higher level operations). A reasonable hypothesis is that 'transfer will be observed between task elements similar in form which may prompt an individual to adopt similar psychological processes'. Whether this is a sufficient basis for predicting transfer effects is an empirical question which will be explored in this thesis. This issue is elaborated in chapter 5, where a model of learning is used as a basis for developing learning conditions which may influence transfer of formally similar task elements.
CATEGORIES OF INTERFACING OPERATIONS

Using the stopping rule described above, we encounter only a small number of different types of interfacing operations, which are described in table 3.1. A useful way to express these is in terms of an operational verb and controlled object. Each of these action verbs would be coupled by an item of equipment (the controlled object) as appropriate to change the state of the plant.

<table>
<thead>
<tr>
<th>Output from operator</th>
<th>Input to operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 - actuate (e.g. open valve; switch on centrifuge)</td>
<td>O4 - read (e.g. read pressure indicator)</td>
</tr>
<tr>
<td>O2 - de-actuate (e.g. close valve; switch off pump)</td>
<td>O5 - monitor to detect change (e.g. monitor temperature indicator)</td>
</tr>
<tr>
<td>O3 - adjust (e.g. increase amps; open valve controller; decrease feed-pump rate)</td>
<td>O6 - monitor rate of change (e.g. log pressure; monitor pressure controller)</td>
</tr>
</tbody>
</table>

This description of interfacing operations bears many similarities with the 'task analysis for knowledge description' approach of Johnson et al. (1984), in which tasks such as 'electronic messaging' etc., are analysed into actions (operational verbs) and objects. This type of description is appropriate for low level operations only (e.g. interfacing operations) which do not require complex skills and are fairly well-practised. For intermediate or higher level operations which call for more complex skills, descriptions need to identify appropriate plans for carrying out these operations. This was also recognised by Johnson et al. (1988) in the description of tasks with an essential planning component.
CATEGORIES OF PLANS

Plans which have been developed in an unconstrained manner in HTA, are difficult to categorise. The study by Shepherd and Duncan (1980) has demonstrated that any complex plan can be replaced by a hierarchy of simpler plans of which there are only a few types. Plans can be reduced in this fashion into a very small number of fundamentals. Choosing the most effective set of plan types for the basis of predicting transfer effects or suggesting training conditions is an issue for research. A taxonomy of plans has been suggested, in this thesis, which will be tested for its suitability for making transfer predictions.

Taxonomies for training must meet three criteria, as these are identified by Annett and Duncan (1967): categories should be mutually exclusive, exhaustive, and should specify different training or transfer conditions. The proposed plan taxonomy is mainly intended to meet the last criterion of enabling transfer between members of the same category. An effort has also been made to create exhaustive categories for describing as many types of process control tasks as possible. The categories are not mutually exclusive, in the sense that behaviours entailed in each category are not necessarily interfering with others.

Annett (1971) has distinguished four types of plans based upon different part-whole relationships, namely: chains where operations are carried out in a fixed order; options where all operations are carried out but in any order; strategies for selecting between operations; and time-sharing plans for carrying out operations simultaneously. In many tasks, however, there is a skill involved in selecting appropriate operations and the nature of this skill must be considered. In some variable sequence plans, for instance, this choice may be determined by a perceptual discrimination, whilst in others by a decision process where evidence of different sources needs to be traded-off. A more elaborate taxonomy, which takes into account these considerations, has been suggested by Shepherd (1980) after applying HTA to a number of process control tasks. The originator of this taxonomy had the intention to invite other researchers as well, to furnish the different types of plans with appropriate training conditions. A review of these training methods by Shepherd (1980) is a starting point for furnishing the taxonomy.

This taxonomy has been adopted in this thesis for the purpose of making transfer predictions. The categories were applied in the analysis of a complex
planning task (see chapter 4) and were related to plans developed by subjects in a pilot study of operating a representation of this task in a microcomputer. Based upon these observations, some of the categories were modified, as it was felt that they may constitute a better basis for transfer than the original version. These definitions are put into test in the present thesis, and if they proved to be inadequate for the above purpose different ones should be proposed. The plan taxonomy consists of nine types of plans, which are summarised in table 3.2 and described below.

Fixed Sequence Plans

These are also referred to as procedures or chains and consist of a sequence of two or more operations, where the next operation is cued by feedback that the previous one has been completed to a desired criterion. Variations of 'whole' and 'part' task training methods employed to teach fixed sequences of complex operations, such as those used in start-up or shutdown procedures, have been reviewed by Stammers and Patrick (1975).

Fixed sequences can relatively well transfer to familiar situations; however, transfer to new situations, where the same fixed plan may sequence different subordinate operations, will depend upon trainees having learned something beyond the procedure itself. Duncan (1971) has shown that when a fault-location skill was reduced into a specific search procedure, transfer was poor for those subjects who learned the specific procedure at the expense of a search strategy; however, subjects who used the procedure to evolve a search strategy had a good transfer score.

In that study, a search strategy involved the acquisition of some 'rule of thumbs' i.e. the 'half-split' rule. It seems then, that transfer of fixed sequence plans to new situations may be determined by learner's characteristics or by the type of instruction offered. Stammers (1976) has found that a 'whole-to-part' training regime enabled trainees to understand the linkages between subordinate operations and acquire the task faster than those trained with a 'part-to-whole' regime. If a trainee can evolve some rules how to link operations, it is conceivable that these may transfer to a totally new situation.
Table 3.2.
Taxonomy of plans.

(1) Fixed Sequence Plans
FORM: Do A, then B, then C,

(2) Contingent Sequence Plans
FORM: Do A, then when state X is achieved do B,

(3) Optional Sequence Plans
FORM: Do all of A,B,C... in any order.

(4) Remedial Cycle Plans
FORM: sample \rightarrow test \rightarrow ok \rightarrow exit
\hspace{2cm} \begin{array}{c}
\text{not ok} \\
\downarrow \\
\text{wait} \leftarrow \text{rectify}
\end{array}

(5) Decision Plans
FORM: Select A,B,C... according to criterion:
(a) If condition X1 then A; If condition X2 then B;
   If condition X3 then C;
(b) If condition Y1 then A and B; If condition Y2 then B and C;
   If condition Y3 then C and A; If condition Y4 then do all;
Where (b) refers to operations at the lowest-level only, whilst (a) to all levels.

(6) Time-sharing Plans
FORM: Do A and B and C together.

(7) Integrating Plans
FORM: Do main duty A, and whenever possible do B at close time proximity.

(8) Fixed Cycle Plans
FORM: Do A, then B, then C then repeat from A, until a specified condition occurs.

(9) Discretionary Plans
FORM: Whenever convenient remember to do A,B,C...
In summary then, transfer of fixed sequences to novel situations may be poor when nothing is learned beyond a specific procedure. This is an empirical question for this thesis, and it has been addressed in the design of the experimental protocols.

**Contingent Sequence Plans**

These are similar to type-I with the exception that the second operation is signalled by a separate target state being achieved e.g. a specified temperature. An important facet of contingent sequence plans is the role of cues as supporting or interrupting performance of the first operation. It is obvious that, when cues specify the key parameters to be monitored in a complex operation, performance of the first operation will be enhanced. In the distillation example, in which process parameters have different response times, a cue such as 'operating pressure' which relates to the primary parameter being monitored (e.g. product quality) may provide early feedback about the outcome of performance.

On the other hand, cues which refer to the following operation, may interrupt performance of the first operation when a safety parameter is violated. An example would be the following plan: 'establish level in column then, when pressure is excessively high, start recovery operation'.

Another important class of cues, particularly important in the context of complex systems where the outcome of performance depends upon teamwork, is the instruction from the shift controller or a colleague who takes product samples 'on site' or who comes across a crucial area overseen so far.

Transfer of these plans will rest with the trainee recognising the importance and applicability of these cues to a new context. The transfer conditions of the fixed sequence plans are also applicable to this type of plan.

**Optional Sequence Plans**

In process control tasks there are certain sequences e.g. pre-start up checks, where the operator has the liberty to carry them all but in any order he may choose. An optional sequence can be transformed into a fixed one, when
experienced operators come up with optimal sequences which can minimise memory requirements and they are used in the same manner in future. On many occasions, it might be beneficial to find out these convenient routes and train them as fixed sequences, particularly to new starters.

Remedial Cycle Plans

This is a very common sort of plan especially in process control. It occurs at every case where a system state has to be achieved e.g. establishing target flow-rates, establishing product quality parameters etc. Any operation concerned with establishing a target fits into this framework. The form of this plan which is displayed in table 3.2 includes the following parts:

SAMPLE is an operation which collects information e.g. 'take sample', 'read instrument'. It may itself be a complex procedure, in which case it should be specified to the operator.

TEST implies making a measurement and comparing it with a target. The target may be memorised or written down on a chart.

RECTIFY refers to selecting and making an adjustment and is therefore itself probably complex. In particular, selecting the adjustment may be highly skilled. Making an incorrect adjustment - too little, too much or the wrong act - will cause the next test to be wrong and the cycle will have to be repeated.

WAIT is crucial, since rectification in any system takes time to take effect. The analysis should specify how long this wait must be.

Sampling and rectifying require a good knowledge of the dynamics of the process and particularly gains and lags. Remedial cycles constitute an essential component of any manual control skill and once acquired, they can transfer to many novel situations in a plant. Transfer to different plants with different dynamics will be questionable in cases where the operator has not acquired any general habits or 'rules of thumb' how to sample and rectify.
Decision Plans

These plans are also called *choices* because the operator has to select one of several operations in accordance with specified prevailing conditions. They are also known as *multiple discrimination tasks* since the operator has to discriminate from a 'stimulus array', and respond by selecting the most appropriate operation. Decision plans may imply a complex decision making component such as diagnosis. In these cases, decision plans may be based upon different types of behaviours such as 'rule-based', 'hypothesis-generation' or 'pattern-recognition' behaviour (Rasmussen, 1981). There is accumulating evidence that decision plans based upon 'rule-based' behaviour (Shepherd et al., 1977) as well as 'hypothesis-generation' behaviour (Rasmussen, 1981) can transfer to novel situations. 'Pattern-recognition' behaviour can become part of any experienced operator but the degree to which they can transfer is questionable (Rasmussen 1981; Shepherd, 1980).

However, when the decision-making process concerns low-level responses, this type of plan may imply either a selection of one of several interfacing operations or even a combination of these. For instance, an operation such as 'relieve high pressure profile' can be achieved either by 'decreasing the flow of the heating agent' or by 'increasing the flow of the cooling agent' or by a combination of both; the crucial factor in this case will be the size of the control action which is felt to be desirable.

An interesting contribution made by the statistical decision theory (e.g. Edwards, 1965) in the analysis of decision plans, concerns the distinction between a decision-maker's ability to discriminate among the alternatives of interest (*a sensitivity parameter*) and the *response criterion* which specifies the amount of evidence required by the decision-maker to choose a particular option, depending upon the perceived costs and benefits associated with the different possible outcomes. Therefore, a decision plan may be thought of as entailing the following cognitive processes:

- identify a set of possible choices;
- assess the likelihood that a particular choice will be the case;
- consider all costs and benefits associated with a particular choice; and,
- integrate likelihoods and costs of possible choices in order to select the most appropriate one.
To illustrate the approach, one can consider the case of fault-diagnosis. According to this line of argument, an optimal operator will go through the following stages:

- identify a set of causes consistent with the information collected so far, e.g. leak in the primary or secondary system in a nuclear power plant;
- assess the likelihood that a particular cause will be the case;
- consider the consequences for the plant for each possible cause e.g. types of safeguards initiated, plant controllability etc; and finally,
- select appropriate cause e.g. unlikely but very serious cause versus very likely but not serious cause.

A growing body of research in process control training (Marshal et al., 1981; Brook et al., 1980; Reiersen, 1985; Su and Govindaraj, 1986) have based their methodologies upon the idea of a Consistent Fault Set or Initial Feasible Set which trainees identify in the initial stage of diagnosis and subsequently evaluate on the basis of further diagnostic information.

In another respect, whenever the analyst redescribes an operation he also has to carry out a decision task and consider possible trades-off between alternative plans. The proposed version of HTA sets him a more difficult task, that of pursuing decision-making up to the level of interfacing operations. However, for those tasks which are adequately performed by operator, the analyst can be relieved in his decision-making by considering criteria suggested by them. This will be a good opportunity for previewing operations and identifying criteria which are effective in the normal plant operation but may not be sufficient for novel situations.

Time-sharing Plans

This is where the operator has to carry out two operations simultaneously. In systems with a fast response time e.g. aircraft or automobiles, time-sharing may imply the need to attend the cues of an operation not currently being executed. If we assume a parallel attention model, then the operator may have to divide attention between the alternatives. Assistance may be offered by specifying cues from one operation that prompt planning in the other or cues which can prompt planning in the same operation.
In slow response systems e.g. navigation of ships and control of chemical plants, time-sharing may present different kinds of problems. Interactions between task components are more complex but take longer time to take effect, and the operator has enough time to pre-plan how and when to attend to each component, provided that he has learned the types of interactions involved. For example, operating a distillation column (see chapter 4), would require the operator to maintain a steady level in the column and keep the product composition in the boiler at specified tolerances. These two operations might be construed as separate, but keeping the level steady might imply changing its output flow which is fed into the boiler, and this may disturb established compositions. The two operations interact - that is, one operation clearly influences the conditions affecting the other. Time-sharing these operations can mean that operators must understand the consequences for the second operation and pre-plan how and when to control it, in order to cancel any side-effects from the first operation. This does not imply division of attention because the operator has enough time to plan how to intervene.

This category as well as the next one of integrating plans have a different meaning in the original taxonomy suggested by Shepherd (1980). It is plausible that time-sharing was reserved for fast response systems and integrating plans for time-sharing in slow systems. In this thesis, time-sharing refers to both types of systems although the implications for training might be different as it was mentioned. Integrating plans (next category) have a totally different meaning in here, and they do not correspond to any category in Shepherd (1980).

Time-sharing plans are assumed to be highly transferable because the operator acquires valuable knowledge about goal interactions as well as ways to cope with them. This can be promoted to a problem solving skill of planning an operation by considering in advance any side-effects upon already established operations.

**Integrating Plans**

This is where the operator has to carry out his main duty but whenever it is possible he performs a significant part of another operation. Thus, the two operations are carried out in close time proximity, but they are independent from one another and there are no side-effects from the component controlled
Integrating plans may appear to be similar to time-sharing plans in the dimension of 'whole' relationships between subordinate components (Naylor and Briggs, 1963), particularly when components can be carried out simultaneously, but they are different in the dimension of goal-relationships; in the latter, the subordinate goals interact but they are independent in the former. This distinction is made in order to capture an important aspect of process control skill, namely, time-sharing of interacting components as opposed to integration of unrelated goals when time allows to do so. From the pilot study it appeared that with the increase of practice, subjects learned to anticipate when an effect would take place and they started carrying out a significant part of an unrelated operation before they would come back to their main operation. This skill was felt to be distinct from the planning involved in time-sharing two goals having a complex interaction. This dimension of goal-relationships had not been addressed in the taxonomy by Shepherd (1980), although is very important for process control tasks.

An important training issue is how operators should practise these two categories, when various components must be carried out in close time proximity. This raises the issue of 'whole' versus 'part' training methods. For integrating plans where components are independent, 'part' training would enable trainees to understand the lags and gains of the process and estimate when it is best to carry out a 'bit' of the secondary component. However, for time-sharing plans the issue seems to be more complicated. Given that the components interact - information displayed in one will be relevant to another - Naylor and Briggs (1963) would favour 'whole' training since the task is of high organisation; however, Annett and Kay (1956) would favour 'part' training since components are interrelated. Annett and Kay's approach is operator-oriented and refers to the possibility that inadequate responses in the context of the first operation may decrease the information value of signals for the second one. One solution which was tried out in the pilot study was to start with a 'whole' method, where the trainee could appreciate what information is relevant to both components as well as what constitute a rich signal for the second operation; at a later stage, he could change to the 'part' mode where he acquires well-practised responses avoiding any reduction of the richness of signals for the second component. Other methods for coping with similar situations are suggested by Stammers and Patrick (1975).
Fixed Cycle Plans

This is the situation where the operator has to carry out a sequence of operations and repeat it from the beginning, until a specified condition occurs. The 'specified condition' will be of the form: until told to stop or when a specified time arrives or when a certain amount of material has been shifted or produced.

At the initial stage of learning a time-sharing plan, trainees would often start with a fixed cycle plan where control of the second component is not taken until the side-effects of the first one are observed; in turn, they wait to see the effect upon the first one before they repeat the cycle from the beginning. With the increase of expertise, however, trainees are able to pre-plan how and when to attend to each component and change their behaviour from a 'feedback' mode to a 'feed-forward' one, which is appropriate for time-sharing plans. Fixed cycle plans are not suitable for interacting components because they are usually associated with many errors and result in oscillating behaviour of the process.

It is important to note that fixed cycle plans are ideal for independent operations and they are close to the 'part' extreme in the 'whole-part' relations. It is useful to construe fixed cycles as a contingent sequence with a feedback loop. An additional reason for including this category, was to account for trainees who did not realise any potential goal-interactions and chose this plan instead of a time-sharing plan as well as for the difficulties involved in mastering the latter plan even when interactions were anticipated but could not be dealt with.

Discretionary Plans

These plans are not mandatory in the sense that they must be done upon certain cues, but they are often desirable and sometimes essential. The purpose of these is usually to raise the level of plant safety and obvious examples include: 'carrying out routine inspections', 'switching off equipment not being used' etc. The problem is making people remember to do them at some stage and often good supervision is the best answer.
In summary then, the plan categories differ in various dimensions e.g., part-whole relationships, goal-relationships, decision-making, perceptual skills, conceptual knowledge (causal-effects, gains, lags) etc. For example, the first three types of sequence plans and the fixed cycle plan are on the 'part' direction of the 'whole-part' relationship, while time-sharing and integrating plans are seen as 'wholes'.

CATEGORIES OF INTERMEDIATE GOALS

Classification schemes of interfacing operations and plans are not sufficient to collate all of the knowledge that trainees may find useful in learning. A classification of higher level operations or goals will serve to collate a variety of contextual aspects of training. Recognition that a current context is organised in a manner similar to a familiar context may enable trainees to try out previously proven strategies and procedures. For example, we would anticipate a trainee already familiar with operating a vaporiser to be able to master operation of another vaporiser relatively easily. The scheme of operations presented in table 3.3 is by no means exhaustive and needs to be developed as training methods for various tasks are researched. Operations such as distillation, evaporation, condensation and establishing levels are common task elements in the operation of a distillation column (see chapter 4), and recommendations for their transferability can be derived from the present thesis.

The hypothesis stated here, is that members of the same category will have similar organisations of plans and transfer will be observed. Although, we can predict the direction of transfer (positive transfer), the degree of transfer will be determined upon transferability of the individual plans which comprise the whole organisation of an intermediate operation. This is also anticipated from the fact that different strategies can be equally good in performing the same process operation, however, their degree of transfer can be different. In retrospect it can be said that, most of the experimental subjects in the thesis have transferred an operation such as 'establishing levels', however, the degree of transfer was determined by the individual plans comprising this operation and by the training method they received.
Table 3.3.
Classification of intermediate goals.

Start up plant

carry out unit operations:
- distillation
- absorption
- filtration
- extraction
- evaporation
- condensation
- heat exchange

Run plant

Deal with Failures
- fault detection
- fault finding
- compensation
- recovery

Shut down plant
(see operations for plant start-up)
For some categories of intermediate operations, transfer may be poorer than others. In that case, a second order classification for these categories may be necessary for making transfer predictions. For instance, research by Shepherd (1975) has indicated that the category of fault-finding can be redescribed as either fault-diagnosis or fault-location; in turn, each of these can be redescribed further, for instance, diagnosis can be either sequence-independent (static) or sequence-dependent (dynamic) diagnosis. When second and third order classifications are introduced we are in a better position to make transfer predictions. For instance, contaminant location may transfer to electronic trouble-shooting since symptoms refer 'downstream', which is the flow of product or the flow of the signal. Fault-diagnosis is distinguished from fault-location because in the former, symptoms can refer to both directions e.g. fault propagation in a distillation column.

Identifying sub-categories for each category of intermediate goals is a matter of further research for optimal training methods. Nevertheless, the proposed scheme is a start of such an attempt to enable transfer predictions to be made.

**HTA AS A BASIS TO CONSIDER MODELS OF NONSPECIFIC TRANSFER**

The proposed version of hierarchical task analysis with the three classification schemes of task elements is a good basis for making predictions about specific transfer. It is also possible to use HTA as a framework within which various models of nonspecific transfer can be considered. Although HTA does not correspond to the actual organisation of behaviour, it does show the complexity of planning involved in a particular task. We will see in chapter 5, that HTA can be a good basis for accommodating models of transfer of strategies as well as of concepts and principles.

Using the plan taxonomy, complex plans governing a few operations can be redescribed into a hierarchy of plans each governing fewer operations. However, not all of these operations present problems to the operator, since the higher order ones do not imply any specific course of action to be taken, but they merely require a verbal response during practice e.g., 'bring sub-system to product specification'. Relationships between goals at different levels can be seen as referring to whole-part relationships between units and sub-units of the overall system, and require an ability to reason at higher levels of abstraction.
The goal hierarchy constitutes a framework within which to consider models of decision-making and transfer e.g. Rasmussen (1983) who claims that the complexity of a system can be reduced by adjusting resolution of information search at a few high level sub-systems and their intended goals.

Reasoning at a high level may also facilitate transfer of principles and concepts as it was suggested by Travers (1977). In the following chapters 4 and 5, it will be demonstrated how concepts and principles required in the operation of a process can be extracted from the cues encapsulated in the stated plans. These cues constitute a good basis around which a theoretical model of the process can be build. HTA can be used as a basis for accommodating models of nonspecific transfer. A great part of chapter 5 is reserved for this purpose.

CONCLUSION

This chapter has argued that HTA can be used for making hypotheses about transfer of common task elements. Previous studies had considered only low levels units such as stimulus-response associations, which is not very helpful for making transfer predictions about complex process control tasks. A classification scheme of task elements is proposed to be used as a basis for predicting transfer of formally similar elements, without the need to consider the types of behaviours entailed in each application. Although the direction of transfer (positive one) may be predicted, it is anticipated that the ultimate degree of transfer will be determined by the original learning conditions under which the task element was acquired. A model of learning and transfer is presented in chapter 5 to enable us develop training methods which will maximise any positive transfer. Finally, HTA can be used as a framework within which to consider models of nonspecific transfer.
CHAPTER 4

HIERARCHICAL TASK ANALYSIS OF A COMPLEX PLANNING TASK

SUMMARY

The suitability of the proposed HTA in identifying common task elements which can provide the basis for transfer predictions is illustrated in the context of analysing a complex planning task, that of starting-up a distillation column. However, optimising transfer of skills requires that trainees receive appropriate instruction so that they become aware of the similarity relationships entailed between different task elements. This chapter demonstrates how the proposed HTA can generate such training information to optimise transfer by identifying alternative types of plans, relationships between different goals, and requirements for conceptual knowledge.

INTRODUCTION

The previous chapter has argued that by taking redescription to the level at which the operator interfaces with the system and by assigning subordinate plans and operations to various categories of task elements, the analyst can identify formally similar 'chunks' within the overall task which can be used as a basis for predicting transfer. The cost of training time in mastering common task elements will be determined by various types of learning conditions which can be generated by a model of learning. Analysing a complex industrial task to the lowest level of detail and examining the various learning conditions that can reduce the cost of training time is a notoriously difficult task for the analyst. In this chapter, we will consider the difficulties involved in carrying out the extended version of HTA, while the various learning conditions that can enhance transfer will be examined in the chapter 5.
This chapter has three aims:

- To demonstrate how a complex and apparently intractable plan of sequencing a great number of operations can be restructured into a hierarchy of simpler plans, by using the existing version of HTA.

- To illustrate how a task can be redescribed into formally similar task elements, by extending HTA to the lowest level of detail and by including the classification scheme of task elements.

- Through completing a thorough analysis in this fashion, it will be shown how the flexibility in the performance of complex skills can be captured, by identifying alternative types of plans equally effective for the same superordinate operation.

THE PLANNING TASK

The planning task to be used to demonstrate the procedure of redescribing a complex task into a set of formally similar task elements is the start-up of a distillation column. The task of the operator is to start-up the column and bring the process to a steady state where certain specified conditions prevail. Every course of action will have to be judged against a number of criteria such as time to take effect, consumption of energy resources, and smooth operation of the process. Since the new version of HTA redescribes every single action to the lowest level of detail - that is, adjusting pumps and valves - a complete description of the distillation column is offered in figure 4.1.

In brief, distillation is a process in which a liquid mixture of two or more substances, each having a different boiling point, is separated into its component fractions of desired purity by the application and removal of heat. The liquid from the base of the column is partially evaporated in the reboiler, which generates a vapour mixture richer in the more volatile component and a bottom liquid product richer in the other component; the produced vapours rise up the column and by the removal of heat in the condenser, they are fully condensed into liquid which is collected in a vessel (drum). A portion of the top product is fed back into the column (reflux flow) and it comes into contact with the rising vapours on a number of trays inside the column; as a result, the vapours become even richer in the more volatile component and the liquid
Figure 4.1. A schematic of a distillation column.
richer in the other component. This process is repeated in every tray, until the more volatile component forms the top product, while the other component forms the bottom product. A more detailed description of the distillation is provided in appendix 2.

Information relevant to performing this task was provided by three students in chemistry and chemical engineering who had the opportunity to meet together and with the experimenter, and practise their knowledge in a representation of the task simulated in a microcomputer (for a description of the plant simulator see chapter 6). This information was utilised by the experimenter in order to construct a HTA of the task of starting-up a distillation column. The informants had a good knowledge of the distillation process but they had limited experience with the real plant. In the process of a few successive meetings, they operated the plant simulator in order to gain practical experience and formulate the required procedures for starting-up the plant. This group of subjects will be referred to as the 'informants' or 'the task analysis' group from now on.

A number of instructional facilities which were part of the training simulator were also evaluated in terms of their contribution to learning the overall task. This study has also provided useful information in order to set the level of difficulty for the main experimental study (see chapter 6 for details).

THE ANALYSIS

When the informants received adequate practical experience with the plant simulator, the experimenter made an attempt to carry out a HTA of the distillation task based on the information provided by this group. In the initial stage of the exercise, fifteen operations were listed as being part of the whole task, as it can be seen from table 4.1.

Each of these operations was considered to be adequately performed by most operators with a few years experience in the industry, hence they were not further redescribed according to the (PxC) rule of HTA. Stating a single plan to indicate the conditions under which these operations should be performed, seemed to be an intractable problem.
Table 4.1.
Operations involved in starting-up a distillation column.

1) Establish feedflow
2) Establish level-1 in column
3) Establish level-II in drum
4) Set reflux to specified value
5) Achieve quality of bottom product
6) Achieve quality of top product
7) Monitor pressure indicator (PI5)
8) Monitor level indicator in column (LII)
9) Monitor level indicator in drum (LIII)
10) Check quality of bottom product (Xb)
11) Check quality of top or distillate product (Xd)
12) Relieve high pressure profiles
13) Minimise energy consumption in the reboiler
14) Minimise energy consumption in the condenser
15) Maintain all parameters to specified values

To restructure this plan into a hierarchy of simpler plans, the methodology developed by Shepherd and Duncan (1980) was followed. Restructuring was achieved by examining the set of subordinate operations to identify groups sharing a common superordinate goal. Smaller groups identified in this way are easier to examine and their plans are easier to state. Finally, an overall plan was sought to govern the sub-goals themselves. This resulted in a comprehensible HTA which was the basis for implementing the extensions proposed in the thesis. Specifically, the following three stages were taken to apply the methodology developed by Shepherd and Duncan (1980) in the analysis of the task under consideration. In the first stage of analysis, the fifteen operations were felt to cluster in four sub-groups:

a) *monitor process parameters* which included operations 7, 8, 9, 10, and 11; it was difficult, however, at this stage to establish the circumstances under which each parameter should be monitored.
b) *establish levels and associated flows* which included operations 1, 2, 3, and 4.
c) achieve qualities of products which included operations 5, 6, 12, 13, and 14; they were assigned to the same group, because initial practice with operations 5 and 6 produced a high pressure profile whose relief required great amounts of energy consumption.

d) maintain all parameters to specified values which was the last operation 15.

At a later stage, following further discussions and practice with the plant simulation, the informants realised that the overall task could be performed in two stages, namely: an intermediate stage where a certain amount of top product is collected in the drum; and a final stage where the reflux flow is adjusted to produce the required product specifications. The two stages were felt to include the following operations:

i) the intermediate stage in distillation included operations such as establish feed flow, establish level-I in column, achieve quality of bottom product without overshooting the pressure and economising on energy resources; and,

ii) the final stage in distillation included operations such as establish reflux, re-establish level-I in column, achieve quality of top product maintaining established quality of bottom product and finally, establish level-II in the drum.

In the end of this second stage of task analysis and after careful consideration of the groups identified in the first stage of analysis, efficient plans were formulated for carrying out the operations of group-c of 'achieving qualities of products'. The bottom part of figure 4.2 shows the specified plan-3 and plan-6 for the above group of operations under the two stages of distillation. In general, it appeared that groups b and c were components of both stages of distillation.

So far, only the bottom part of the task analysis was specified (see figure 4.2), and the two top plans A and B for the two stages of distillation were teased out in the third stage of analysis. Identifying plans A and B revealed opportunities for the informants to optimise running the system not hitherto recognised by their knowledge of the plant and their practical experience with the simulator. Although, none of the informants had applied the prescribed plans A and B in operating the plant, they all agreed that these plans constituted a very effective strategy for starting-up the plant.
Figure 4.2. Task redescription based upon the previous version of HTA.
Plan-O was a simple plan and no particular difficulties were encountered in mastering it.

In the end of the task analysis, it became obvious that the first group of 'monitoring process parameters' had no longer any reason to exist as a separate group, since its members could be used separately in various plans to specify the conditions under which subordinate operations could be carried out. In addition, the last group of 'maintaining all parameters to specified values', which did not imply any specific course of action, was excluded from the analysis since the prescribed plan hierarchy would maintain all parameters adjusted to their target values.

In summary then, it was apparent that without a plan stating the conditions under which the subordinate operations should be carried out, the original fifteen operations were neither exhaustive nor distinct. Identifying groups of operations sharing a common superordinate goal is a continuous process in task analysis, which can focus at either the intermediate or higher levels of the hierarchy as the analyst gathers additional task information. In the present analysis, for instance, the four groups formulated at the first stage of the analysis were subsequently modified to fit the two higher-level groups of the intermediate and final stage of distillation.

A hierarchy of simpler plans was argued by Shepherd and Duncan (1980) to have the following merits: it can specify criteria against which mastery of a task element can be measured; it can provide a set of conditions which can directly guide a trainee to mastery; and finally, it can indicate parts to be practised together in a part-task training regime.

The HTA summarised in figure 4.2 is the basis upon which the extensions proposed in this thesis can be implemented. Therefore, the extended version of HTA begins at this stage in which all 'primitive' operations 1, 2, 3.1, 3.2, 3.3, 4, 5, 6.1, 6.2, 6.3 and 7 can be redescribed to the lowest level of detail, and plans can be broken down further and assigned to the categories specified in the plan taxonomy.
EXTENDING TASK DESCRIPTION WITH THE NEW VERSION OF HTA

The task redescription according to the principles of the proposed version of HTA is summarised in figures 4.3 and 4.4. Apparently, there is a correspondence between operations redescribed in figure 4.2 (existing version of HTA) and figure 4.3 (new version of HTA). Specifically:

- operations A, B, and I are common in both figures.
- operations 2 and 3 are grouped together in operation-2 in figure 4.3 and correspond to operations 2.1 and 2.2. This grouping was necessary because of the interrelationships between the subordinate operations.
- a new operation-3 is added to figure 4.3, in order to create similar patterns of performance for the two stages of distillation.
- operation-4 is common to both figures.
- operations 5 and 6 are grouped in operation-5 in figure 4.3 (for similar reasons as operations 2 and 3), and correspond to operations 5.1 and 5.2, and finally,
- operation-7 is identical to operation-6 in figure 4.3.

'Primitive' operations which were not further redescribed in HTA, should be taken to the lowest level of adjusting pumps and valves. However, such a description of a complex industrial task would require a huge record of all possible activities, and this would run the risk of losing sight of the overall task. Choosing an appropriate 'grain of analysis' representative of the lowest level operations, would create a more concise task description, without the risk of missing out important 'bits' of the task.

The grain of analysis

Efforts to redescribe the 'primitive' operations indicated that a task description ceased at the level of 'adjusting rates of flows' was satisfactory from the point of view of capturing the whole planning behaviour entailed in a task. Each 'adjust rate of flow'-operation was found to follow a similar pattern of performance, namely, a remedial cycle plan specifying conditions for adjusting pumps and valves. Since, the pumps were either on or off in the plant simulator, they did not present any problems at all and they were omitted from the description. It will be recalled, that remedial cycle plans consist of mainly four components, that is, sample, test, rectify and wait. These components were
Figure 4.3. Task redescription of higher-level goals, based upon the proposed version of HTA.
used to redescribe all operations of the form 'adjust rate of flow' as it can be seen from the following example.

From figure 4.4, the operation 'adjust rate of heating flow' (2.2.1.1.2) was redescribed as:

```
READ (Vb)
TEST (Xb, FR3, PIS)
ADJUST (Vb)
```

Sampling entails reading process parameters which are useful in achieving the superordinate goal (2.2.1.1) of adjusting evaporation in order to improve the quality of the bottom product (Xb). These process parameters include the controlled parameters (in this case, the position of valve Vb only, since the system does not indicate the rate of heating flow), the target parameter (Xb) and some reference parameters (FR3, PIS) which indicate the degree of progress towards the superordinate goal. These 'reference' parameters may have shorter lags and larger gains and thus, progress towards a goal can be monitored relatively easier by consulting them rather than the target parameter. For instance, an increase in pressure (PIS) indicates that evaporation has started, while the flow-rate FR3 is reversely proportional to the quality (Xb). In the previous description, the operator should 'READ' the controlled parameters, and then 'TEST' the target and reference parameters. 'ADJUST' the controlled valve (Vb) is an operation similar to rectify. It is worth noting that, the same operation 'adjust rate of heating flow' (2.2.1.2.1) may have different test parameters (that is, PIS, TIS) under another superordinate goal (2.2.1.1). Specifying reference parameters to monitor progress towards different superordinate goals enables the analyst to identify relationships between process parameters and formulate a conceptual model of how the system works. The previous example illustrates the use of the proposed HTA in generating conceptual knowledge relevant to the performance of the whole task. All operations of the form 'adjust rate of flow' are described with the same pattern of 'read', 'test' and 'adjust', as it can be seen from figure 4.4.

**Goal-relationships**

Choosing as grain of analysis the 'adjust rate of flow'-operation, and describing it according to the previous pattern of performance, enables the analyst to
Figure 4.4. Task redescription of intermediate-level goals, based upon the proposed version of HTR.
identify goal-relationships at all levels of the task hierarchy. It will be recalled from chapter 3, that goals can be either independent or interacting - that is, one goal clearly influences the conditions affecting the other.

Careful consideration of the operations entailed under the intermediate stage of distillation (figure 4.4) has indicated a third type of goal-relationship, namely, goal-overlap. For instance, goals 2.1 and 2.2.1.1 overlap in the sense that they have in common the operation 'adjust rate of flow-2'. However, there is also a non-overlapping area which includes operations such as 'adjust rate of feedflow' and 'adjust rate of heating flow'. It is conceivable that, if the operator decides to exploit the non-overlapping area and achieve goal-2.2.1.1 by 'adjusting the rate of heating flow' only, the problem is reduced to goal-independence. If he decides to exploit the overlapping area and achieve the same goal by adjusting both flow-2 and heating flow, the problem is promoted to goal-interaction. It is important to note that goal-overlap can be transformed to goal-independence or goal-interaction according to the type of plans chosen by the operator.

Goal-overlap was prevalent throughout the task description, as it can be seen from figure 4.4. In summary, the following overlapping areas were recorded:

- 'adjust rate of feedflow', which is common to goals 1 and 2.1;
- 'adjust rate of flow-2' which is common to goals 2.1 and 2.2.1.1; and,
- 'adjust rate of heating flow' which is common to goals 2.2.1.1 and 2.2.1.2.

Goal-overlap is an important criterion for choosing between alternative types of plans, as it will be seen in the next section. This type of goal-relationship could not clearly be seen from the description provided by the existing HTA. By modifying the stopping rule to extend redescription to the lowest level of detail, the analyst can gain a valuable insight into these goal-relationships.

An opportunity for looking at various aspects of the instrumentation system was also given, which made certain implications for including additional operations in the task description. From further discussions with the informants, it was realised that, whereas the indicator of the quality of the bottom product (Xb) was taking readings from the reboiler, the indicator of the quality of the top product (Xd) was taking readings from the drum rather than the condenser. As a result, the quality Xd was contaminated by existing liquid in the drum and it was necessary to flush out this liquid in order minimise
contamination. Thus, operation-2.2.2 was included in the task description in order to enable the operator to get a better estimate of the true quality Xd coming out of the condenser. Because there is a one-to-one mapping relationship between the product qualities, the quality Xd could also be monitored to indicate progress towards achieving goal-2.2.

In summary then, the extended version of HTA enables the analyst to see more clearly the goal-relationships entailed in a task and produce a more exhaustive set of subordinate operations. In addition, certain implications can be made with respect to what constitutes appropriate conceptual knowledge, by specifying 'reference' parameters to enable monitoring of progress towards the intermediate goals of a task.

Categories of plans

Applying the taxonomy of plans in the task description in figures 4.3 and 4.4, requires the analyst to record the various forms of goal-relationships entailed in the task. Experience with the new version of HTA indicated that the criterion of performance chosen for an operation (e.g. degree of accuracy or stability of a process parameter) will also determine the appropriate types of plans. In general, when an operator does not achieve a high degree of accuracy and stability before he attends to another operation, appropriate plans would include: remedial plans, fixed cycle plans, integrating plans and time-sharing plans. On the other hand, when a high degree of accuracy and stability is achieved in the first operation, appropriate types of plan would include either fixed or contingent or optional sequence plans. Finally, decision plans may entail an ability on the part of the operator to choose between alternative types of plans according to the prevailing circumstances.

Bearing in mind these observations, the types of plans recorded in the task of starting-up the distillation column were assigned to the categories shown in table 4.2.

Plan-O is a fixed sequence plan and requires the operator to establish the intermediate stage first before he attends to the final one. Plans A and B can be either of a fixed sequence or fixed cycle type. The fact that the qualities of both products should be achieved in plan-B, may obscure any similarity with plan-A; because of an one-to-one mapping relationship between
Table 4.2. Plans derived from the task analysis.

PLAN-0 is a Fixed Sequence Plan: Do A, then B.

PLAN-A can be one of the following types:
(a) Fixed Sequence Plan: Do 1, then 2, then 3.
(b) Fixed Cycle Plan: Do 1, then 2, then 3, then repeat from 2, until levels 1 & 11 and quality of bottom product are steady on their target values.

PLAN-B can be one of the following types:
(a) Fixed Sequence Plan: Do 4, then 5, then 6.
(b) Fixed Cycle Plan: Do 4, then 5, then 6, then repeat from 5, until levels 1 & 11 and quality of both products are steady on their target values.

PLAN-2 can be one of the following types:
(a) Fixed Sequence Plan: Do 2.1, then 2.2, according to the criterion: 'level-I should be stabilised on its target value, before attempting operation 2.2'.
(b) Fixed Cycle Plan: Do 2.1, then 2.2, then repeat from 2.1, until both level-I and quality of bottom product are set. Criterion: 'both operations should be close to their targets and relatively stable before changing over'.
(c) Time-sharing Plan: Do 2.1 and 2.2 together, according to the criterion: 'whenever Vo is adjusted as part of 2.1, Vb should also be adjusted in the same direction as part of 2.2, in order to cancel out side-effects from 2.1

PLAN-5: Similar types of plans can apply as for plan-2, however, the time-sharing plan is going to be the most effective. This is because, in order to maintain the established quality of the bottom product, Vo and Vb should be adjusted jointly, so that any side-effects from 5.1 upon 5.2 are cancelled out.

PLAN-2.1 is a Decision Plan: Select 2.1.1 or 2.1.2 or both according to the criterion: 'If level-I below 20 cm (height of exit pipeline) then increase flow-1'; 'If level-I above 20 cm then consult table below':

<table>
<thead>
<tr>
<th>Level-I</th>
<th>Flow-1</th>
<th>Flow-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>low/high</td>
<td>high/low</td>
<td>low/high</td>
</tr>
</tbody>
</table>

PLAN-2.2 is an Integrating Plan: Do 2.2.1 and whenever possible do 2.2.2.

PLAN-2.2.1 can be one of the following types:
(a) Fixed Cycle Plan: Do 2.2.1.1, then when PI5 is high do 2.2.1.2, then repeat from 2.2.1.1.
(b) Time-sharing Plan: Do 2.2.1.1 and 2.2.1.2 together, by adjusting rates of heating and cooling at equal proportions.

PLAN-2.2.1.1 is a Decision Plan: Select 2.2.1.1.1 or 2.2.1.1.2 or both according to the criterion table:

<table>
<thead>
<tr>
<th>Quality (Xb)</th>
<th>Flow-2</th>
<th>Flow of heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>below/above target</td>
<td>increase/decrease</td>
<td>decrease/increase</td>
</tr>
</tbody>
</table>

Flow-2 is adjusted in small steps to ensure minimum energy consumption in the reboiler. Qualities Xb & Xd vary proportionally, under complete condensation.

PLAN-2.2.1.2. is a Decision Plan: Select 2.2.1.2.1 or 2.2.1.2.2 or both according to criterion table:

<table>
<thead>
<tr>
<th>Pressure PI5</th>
<th>Flow of heating</th>
<th>Flow of cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>constant or decrease</td>
<td>increase</td>
</tr>
</tbody>
</table>

To minimise energy consumption in the condenser, the flow of cooling should be as low as possible, but high enough to decrease the pressure.
Xb and Xd, plan-A can also be stated as 'achieve intermediate qualities of both products'. Experience with the plant simulator indicated that both plans have many similarities.

Plan-2 specifies the conditions for carrying out two overlapping goals 2.1 and 2.2, which have in common the 'adjustment of rate of flow-2'. If goal-overlap is reduced to goal-independence, a fixed sequence and fixed cycle plans can be equally effective. These two plans differ in the degrees of accuracy and stability achieved in the first operation. If the problem is promoted to goal-interaction - that is, flow-2 can be adjusted as part of both goals - the most appropriate plan is a time-sharing one.

Plan-5 can take one of the three previous forms as well. However, because the quality Xb has already been established, a time-sharing plan is preferable in order to minimise any side-effects from setting level-I in drum. The other two types of plan may also do the job, but they require a lot of practice to avoid any oscillations of the quality of the bottom product.

Plan-2.1 is a decision plan, where the trainee is also provided with a criterion table from which to decide how to carry out the task. From discussions with the informants, it appeared that each person favoured different plans to cope with operation-2.1, all of which appeared to be equally good. Therefore, this plan was specified as a decision plan. However, if performance of this plan is not satisfactory, trainees can be provided with a fixed sequence plan and be allowed to evolve their own plans with the increase of expertise.

Plan-2.2 is an integrating plan which specifies conditions for carrying out operations 2.2.1 and 2.2.2. It will be recalled that a high level in the drum may obscure the true quality of the top product (Xd) coming out of the condenser; when level-I is frequently flushed out, the operator may have a better basis for estimating Xd. In this sense, operations 2.2.1 and 2.2.2 can be perceived as being independent from one another.

Plan-2.2.1 specifies either a fixed cycle plan or a time-sharing one. The latter type requires a considerable amount of experience because the operator must be in a position to judge precisely how to adjust the rates of heating and cooling simultaneously. For the operating conditions of the present experiment, however, the flow-rates can be adjusted in equal proportions.
Plan-2.2.1.1 is a decision plan. If the operator perceives plan-2 as a fixed sequence or fixed cycle plan, then flow-2 should be kept constant; if a time-sharing plan is chosen, then flow-2 can be adjusted in joint with the heating flow.

Plan-2.2.1.2 is also a decision plan. The heating flow should preferably be kept constant so that any interaction between goals 2.2.1.2 and 2.2.1.1 is avoided. However, if the pressure rises too high, the heating flow can be decreased to reduce the amount of vapour entering the column.

From the above discussion, it appears that different types of plans may equally well serve the same superordinate goal. The analyst is free to focus at different levels of the plan hierarchy and collect the type of information he may need to decide between alternative plans. The opportunity to get down to the lowest level of detail, in conjunction with the plan taxonomy, can assist him to refine previously stated plans and suggest more satisfactory ones. Understanding the different types of plans equally applicable to the same situation, may enable task description to capture the flexibility of performance entailed in process control skills, an achievement which was not easy with the previous version of HTA.

Categories of intermediate goals

So far, we were concerned with the description of the first stage of distillation, whilst the final stage was analysed to a limited extent. Careful consideration of figure 4.3 may suggest that the two stages of distillation share three intermediate goals. Specifically, goals 2.1 and 5.1 have to do with adjusting levels in the column; goals 2.2 and 5.2 have to do with carrying out evaporation and condensation; and finally, goals 3 and 6 have to do with adjusting levels in the drum. Further analysis of goals 5.1, 5.2 and 6 indicated that they entail similar organisations of plans and operations to their corresponding goals of the intermediate stage; therefore, these goal-descriptions need not be presented here.

The fact that the three intermediate goals can be redescribed in similar patterns of performance over the two stages of distillation can be used as a basis for setting hypotheses about the transferability of each intermediate goal to the final stage. The learning conditions which can maximise any positive transfer are discussed in the chapter 5.
CONCLUSION

The proposed version of HTA has the benefit of enabling the analyst to view the whole hierarchy of goals and plans at the lowest level of detail and identify task elements of a similar kind. In addition, it provides a better basis for capturing the flexibility of performance in process control tasks by allowing someone to consider various types of plans which promote different aspects of the task. Both issues are discussed in detail in the following section.

Identifying formally similar task elements

At an early stage we could describe the overall task by listing the original fifteen operations, however, teasing out a plan to specify how and when these operations should be carried out seemed to be an intractable problem. Following the method of restructuring advocated by Shepherd and Duncan (1980), it was possible to focus on smaller groups of operations whose plans were easier to state. In this way, the overall plan was restructured into a hierarchy of five simpler plans (figure 4.2) which could be easier mastered following various part-task training regimes. The original task description in figure 4.2 did not provide a strong basis to identify any similarities between different task elements. It was only when redescription was extended to the lowest level of detail and when task elements were assigned to appropriate categories, that we were able to identify formally similar task elements. The overall task was redescribed into two stages which shared three different sub-goals, each having a similar structure of plans and operations in the two stages. A trainee who has mastered the three sub-goals of the first stage would be expected to transfer them relatively well to the second stage.

It was also apparent that the new version of HTA enabled us to understand the different types of goal-relationships entailed in the task, which made the application of the plan taxonomy relatively easy. To create a more concise task description, the operation 'adjust rate of flow' was chosen as the 'grain of analysis' instead of the interfacing operations which were suggested in previous chapters. Although the 'grain of analysis' can be adjusted according to the complexity of the task under examination, the way that this relates to the interfacing operations should be described formally e.g. through a remedial cycle plan in the case of the distillation example.
By looking into the 'reference' parameters specified in each remedial cycle plan, the various relationships between process parameters could be recorded and serve as a basis upon which knowledge about 'how-the-system works' could be built on. This method of examining the conceptual knowledge required to carry out a task is further exploited in chapter 7, in which various forms of supporting performance of task elements are examined.

Capturing the flexibility of performance of process control skills

Through completing a thorough analysis in this fashion, it has been shown that alternative types of plan can be identified which can equally well serve the same superordinate goal. When an analyst needs to state a plan, he must consult all task information relevant to the performance of the task such as relationships between operations, perceptual or conceptual difficulties and so forth.

A set of plans can be identified for carrying out each operation, consistent with the task information gathered so far. At the early stages of the analysis, however, the analyst may find it difficult to distinguish between the most effective plans of the Consistent Plan Set (CPS, in short) for each operation. By extending redescription to greater levels of detail, additional task information is gathered which is useful in carrying out not only the operation under examination, but also all the superordinate ones. In this way, the CPS for an operation can be refined in the sense that it can either be reduced to one or the conditions under which each of its member is applicable become clearer. For instance, the CPS for operation-2 (see table 4.2) consists of a fixed sequence plan, a fixed cycle plan and a time-sharing plan, all being equally effective. The CPS is a useful concept because it captures the flexibility of process control skills.

When redescription ceases at the level where operations are adequately performed by the operator, the analyst is constrained from gathering additional information useful in refining the CPS of the superordinate goals. With the extended version of HTA, it is possible to reconsider previously stated plans and specify more satisfactory ones.
The proposed version of HTA has identified a number of formally similar task elements which can be assumed to have a high potential for transfer. However, the cost of training time for transfer, will be determined by the types of instruction offered to support mastery of these elements in the original task. This issue is further discussed in the next chapter.
CHAPTER 5

SUPPORTING TRANSFER OF TASK ELEMENTS WITH DIFFERENT TYPES OF TRAINING INFORMATION: THE CASE OF THE 'GOAL RESPONSE SET DISTANCE' MODEL OF LEARNING

SUMMARY

The previous chapter has demonstrated how HTA can be used to identify formally similar task elements and larger 'chunks' within a complex industrial task in order to facilitate transfer predictions and training design. Although we can assume that the direction of transfer will be positive, the degree or size of transfer and the associated additional effort to master common task elements in a new context will be determined by the type of training information available in the original context. Transfer of task elements can be supported by providing appropriate training information which would enable trainees to recognise that the new situation is likened to an old one, and thus, task elements within their repertoire can also be effective for the new situation. Recognising similarities between different contexts is not an easy job for the trainee who may have to reason at an abstract level, above the surface features of these contexts. Recent transfer studies of routine cognitive skills such as text-editing (e.g. Ziegler et al., 1987; Karat et al., 1986; Pollock, 1988) have pointed out the role of instruction in reducing the cost in training time of mastering similar task elements in a new context.

The purpose of this chapter is to examine different forms of training information which can support transfer. To this extent, a model of learning is proposed to serve as a basis for designing training methods to optimise transfer of task elements. The proposed 'Goal Response Set Distance' model of learning expands beyond the issue of transfer of task elements to the process of nonspecific transfer and response construction, and makes recommendations for the training of 'experts'.

This chapter has been developed from ideas reported in Shepherd and Kontogiannis (1987).
INTRODUCTION

The major mechanism of transfer which has been considered so far, was based upon the assumption that trainee's knowledge of how to perform a process control task can be represented as a collection of task elements such as plans, interfacing and intermediate-level operations. When 'chunks' within a task can be redescribed in terms of similar organisations of plans and operations transfer will be observed between these 'chunks'. No hypotheses have been made with respect to the size of this transfer or to the conditions which may give rise to various forms of nonspecific transfer.

In order to explore these issues in a model of transfer, we need to compare the HTA approach to transfer with other methodologies developed in the context of other cognitive skills as well as draw more heavily upon the empirical findings of the transfer studies reviewed in chapter 2.

A major contribution to the study of transfer has been made by research into text-editing skills which models user's knowledge of how to perform a task in terms of production rules. A production rule is considered to be the elementary unit of cognitive skill and it is akin to a primitive plan which specifies the conditions under which a particular action is invoked. Anderson (1982) has suggested a three stage model for the acquisition of production rules, drawing upon earlier skill learning ideas of Fitts (1962). He sees an initial instruction phase where declarative knowledge e.g. facts, concepts and principles, is conveyed to trainees. By practising the task, declarative knowledge is 'compiled' into productions and ceases to play an important role in further development of skill. The end product of this 'compilation' process is a set of productions (procedural knowledge) which are independent of the declarative knowledge-base. With extended practice, a third stage is achieved where individual productions are collapsed to form larger ones, which are further 'tuned' so that performance is speeded-up and memory capacity is increased. Although this model of skill acquisition has been criticised by many researchers (Rasmussen, 1986; Payne, 1988) for restricting the role of declarative knowledge in the initial stage of learning, it has provided a good basis for developing computational models of learning and transfer.

Kieras and Polson (1985) have developed a quantitative model of transfer based upon this idea of modelling cognitive skills in terms of productions. According to these authors, transfer between two tasks will 'strictly' be determined by the
number of production rules shared by the two tasks. A strong assumption of
this model of transfer is that nonspecific transfer is not considered to be an
important contributor to performance, and that common productions are
recognised and incorporated into the representation of a new task at no cost in
training time. Support for these assumptions was provided by a study by Polson
et al. (1986) which manipulated the training order of three text-editing tasks
within the same word-processing system.

Other transfer studies in the context of text-editing skills have not supported
the postulated linear relationship between learning time and number of new
productions to be learned. A study by Ziegler et al. (1987) has proposed a
stochastic rather than a deterministic relationship, in order to deal with the
large individual differences observed and the cognitive effort involved in
applying old productions to new contexts. Another study by Karat et al. (1986)
has implied a source of nonspecific transfer between two word-processing
systems, having different function syntax. A major source of transfer in that
study was the knowledge of the basic conceptual structure of text-editing. The
fact that many studies have not found nonspecific transfer effects can partially
be attributed to the limited experience of the subjects with the original task; it
is conceivable that users may need extensive practice with a system, if they are
to develop some sort of conceptual knowledge about text-editing which can be
useful in operating other systems as well.

In summary, it appears that trainees may have difficulties in recognising and
applying common task elements or productions to new contexts, and that
various types of training information about either the original or transfer task
may enhance such transfer. A study by Pollock (1988) has shown that low-
level instructions about the transfer task which were related to the original
task, produced the greatest transfer. Information at a high level of abstraction
could not easily be utilised, particularly when it was not related to the original
task. This finding can clearly demonstrate the difficulties involved in
applying common task elements to new contexts, and the role of instruction in
enhancing such transfer. In the next section, a model of learning is proposed to
serve as a basis for developing training information to optimise transfer.
A LEARNING MODEL TO SUPPORT THE DESIGN OF INSTRUCTION AND OPTIMISE TRANSFER

Implicit in the hypothesis of transfer of common task elements identified with the use of HTA, is a viewpoint on how trainees learn. This is necessary in order to prompt what types of instruction would enhance such transfer. This section will outline a model of learning which can form a basis for taking such training decisions.

Relationship between HTA and models of learning

The only certainties that we have about an operator's behaviour is the extent to which he is successful in achieving a goal and the type of interfacing operations he has used. Although the HTA can describe this intervening distance into a hierarchy of subordinate goals and plans, we have no basis to assume that the two organisations are similar in any respect. HTA is concerned with the description of the goals of behaviour (terminal behaviour) required for an operator to contribute to the overall system goal, and it does not attempt to prescribe the psychological demands experienced when learning these goals.

The hierarchy in HTA has no significance for the manner in which the learner's behaviour is organised. However, we can make the following assumptions:

- The task description in HTA between a particular goal and a set of subordinate operations reflects the complexity facing the learner trying to construct a useful response to that goal, using the corresponding response facilities.

- HTA can be used as a criterion of performance, because it can specify which observable responses are brought into play for a particular set of conditions, and these can be compared against what the human being does. Difficulties encountered by trainees in utilising previously gained expertise can also be examined, by relating them to the similarity relationships between task elements.
Finally, when we know that the trainee has already mastered some task elements of the goal hierarchy, then learning required will be achieved more easily.

Although the organisation of goals within HTA is hierarchical, trainees are at liberty to adopt the kind of organisation they choose - this being either linear or hierarchical or script-based or opportunistic (Cohen and Feigenbaum, 1982). However, with the development of expertise they can be expected to behave in a hierarchical or feed-forward manner (Bainbridge, 1978; Larkin et al., 1980), which will be closer to the hierarchy of HTA.

All we can say of behaviour, with confidence, is that learners demonstrate how to use a set of interfacing responses to attain a specified goal or instances of a class of goals. Any organisation beyond the behaviour to achieve a goal is a matter for conjecture. However, we need to outline a hypothetical model of leaning in order to support design of instruction for optimising transfer. If such a model cannot specify effective learning conditions for transfer, it should be modified or rejected in favour of others.

A Model of response learning

We assume that when set a goal to attain, the trainee seeks an appropriate available response from his response repertoire. If no single response seems suitable, then he must construct a response from those that are available in order to meet the set goal. An appropriate outcome will increase the likelihood that this response will itself be treated as an individual response on future occasions under similar circumstances and could, in turn, feature along with other responses in a plan to cope with an unfamiliar event. This process is represented graphically in figure 5.1.

The selection and sequencing of available responses in construction is a complex private event, but we can speculate on some of the issues in the construction and execution of a plan. (i) We can assume some search process is involved, where likely responses are sought against some criterion in the construction of a plan. (ii) If a well-practised response (e.g. a task element) exists which seems to be suitable, it can directly be applied to achieve the set goal. On some occasions, a task element can slightly be modified in order to become
Figure 5.1. A model of response learning.

Figure 5.2. Constituent items of response set.
satisfactory in a new context. This is the phenomenon of the transfer of task elements, in terms which are defined in the thesis. The person, highly practised at a specified range of tasks, can explore transfer and need only work through steps 1-2-3-5-6-7 (figure 5.1). (iii) The person for whom the search in step 2 has been unsuccessful, must undertake the complex task of constructing a response in step 4. In his attempt to construct a response from those available in his repertoire, the trainee can make use of general strategies or concepts and principles learned in similar contexts. We usually refer to this phenomenon as nonspecific transfer.

In summary then, the proposed model of response learning entails the following processes: response search, response selection or construction, response execution and monitoring, and response revision and storage.

The Goal Response Set Distance

The concept of Goal Response Set Distance (GRS distance, in short) helps us make sense of the difficulty facing the learner when constructing a response. A trainee set a high level goal, such as 'operate plant', faces a large GRS distance. To learn in such circumstances probably requires the trainee to construct a number of intermediate goals in order to organise responses from the existing ones in his repertoire. If the trainee is set a lower level goal such as 'establish level in column', he faces a smaller GRS distance. Generally, we assume that it is easier to master a task with a small GRS distance than a large one. The role of the instruction process, in this respect is to control the distance presented to the trainee. We cannot measure GRS distance precisely, but certain instructional strategies will reduce it or make it easier for the trainee to cope. Finally, the GRS distance is related to the type of transfer that may be observed: a small distance will mean that trainees have acquired similar task elements from previous experiences which can relatively easily be applied to a new situation (specific transfer); a large distance requires a response-construction process which can be supported by both specific and nonspecific transfer.

Constituent elements of the response set

The learner not only constructs new responses, but also learns planning elements, recognising with experience that operations in the real domain fit together in
limited ways. When experience has not been accumulated to the extent that these planning elements can be developed, the learner can be assisted in his response construction either by the provision of certain useful concepts and principles of the controlled system or by representing the system at a higher level of abstraction (Rasmussen, 1986). With extended practice with the task, the trainee may acquire such system prototypes which can be useful for mastering new task elements within the existing system.

These three elements - that is, task elements, planning elements and system prototypes (see figure 5.2) can be seen as the basic components of a response repertoire or set. The precise nature of these elements and their potential interactions are very important in understanding the role of instruction in learning and in transfer. A detailed discussion of each element follows below.

Task elements

Task elements are well-practised responses which can take one of the three forms specified in chapter 3 - that is, plans, interfacing or intermediate operations. If the trainee has already mastered the appropriate task elements for the job at hand, he will only have to retrieve those elements from his memory and execute them. Task elements shared by two tasks can be identified with the proposed version of HTA, and they can be assumed to result in positive transfer. Research in text-editing skills (Ziegler et al., 1987; Karat et al., 1986; Pollock, 1988) has pointed out that trainees may have some difficulties in recognising that two contexts share similar task elements, and that some forms of instructions are effective for maximising such transfer. On occasions, where some modification of the existing task elements is necessary for their application to a new situation, trainees may be required to gain access to information about the functioning of the system implied in these task elements.

This raises the question of the way that task elements are encoded and stored in the trainee's repertoire and the factors that will influence these processes e.g. activity at encoding, knowledge of results at encoding, and form of accompanying knowledge presented. All these factors will determine the size of transfer of common task elements in a new context. Extensive practice of these elements may bring into play a 'compilation process' (Anderson, 1982) in which all elements are represented as procedures or macro-productions which
account for rapid and error-free performance. An empirical question here, will be the extent that 'compilation' will enhance or diminish transfer in new contexts with varying degrees of similarity with experienced ones.

Planning elements

In the absence of any well-practised responses, the trainee faces a larger GRS distance and he has to construct a plan from those available in his response set. The size of the response set will play an important role in the process of plan construction. If the trainee has no experience with the particular problem domain, he will have to rely on general problem solving strategies such as means-ends-analysis, generate-and-test and so forth (Newell and Simon, 1972). If, however, the context of application is familiar but no single task element is suitable for the new task, the trainee can reduce the GRS distance by relying on his planning elements.

Planning elements are domain-specific strategies which have been proved to work relatively well in fitting together various task elements in a particular domain. For instance, forward-reasoning was shown to be an effective strategy in the field of geometry and physics (Anderson, 1983; Larkin et al., 1980), while breadth-first reasoning was effective in the field of programming (Anderson et al., 1984; Jeffries et al., 1981). Planning elements can also be developed as a result of extensive practice of a set of 'diagnostic rules' (Shepherd et al., 1977; Patrick and Haines, 1988), when trainees can appreciate that the first steps in fault-diagnosis in most plants include operations such as locating the fault within a sub-system, and then checking for pumps/controllers/instrument failures. Planning elements presuppose some sort of familiarity with a particular system, but not necessarily the possession of efficient plans for operating it. It is conceivable that, explanations about the reasons for choosing between alternative types of plans may contribute to the acquisition of such planning knowledge, useful in situations where a large GRS distance is faced.

Transfer due to planning elements can only be inferred in the absence of other explanations. Where someone appears to have 'learned-how-to-learn', they are also usually in a position to take advantage of common task elements, making it very difficult to demonstrate the independent existence of planning elements. We may try to take advantage of these skills by training in a fashion to
encourage their development, but we cannot assume that improvements in performance will be due exclusively to them.

System prototypes

System prototypes include stereotyped conceptions or models of the structural and functional relationships of the physical components of the controlled system. They are also referred to as conceptual or mental models (Rasmussen, 1986; Bainbridge, 1988; Gentner and Stevens, 1983). In the domain of process control, a variety of independent studies have shown that training of theories, fundamentals and principles did not enhance performance, and some times actually degraded it (Brigham and Laios, 1975; Crossman and Cooke, 1974; Kragt and Landeweerd, 1974; Morris and Rouse, 1985; Shepherd et al., 1977). Although performing solely on the basis of these system prototypes may take trainees a considerable amount of practice to evolve their own procedures, transfer to new contexts may be enhanced to the extent that existing procedures are rapidly modified with the use of such prototypes. Therefore, system prototypes can be an important constituent of a response set, when transfer considerations are taken into account. For instance, Kieras and Bovair (1984) have found that having a model of how a device works, in addition to the operating procedures, facilitated learning, retention and invention of procedures for operating the device.

It is important here to note that, system prototypes can be represented at different levels of abstraction as well as degrees of task relevance, both of which may influence their contribution to performance. Rasmussen (1986) has proposed five levels of abstraction and argued that, one way to cope with control of systems with a large number of information sources is to adjust system resolution, by describing it in a higher level of abstraction. Although, there is little evidence that experienced operators are actually reasoning at such levels of abstraction, if this is proved to enhance performance they can be trained to do so. The utility of system stereotypes will also be determined by the extent that it allows trainees to infer the exact steps required to operate a device. Indeed, Riley (1984) has argued that 'how-it-works' information must be selected so that it can explain how or why a goal must be accomplished.

On the other hand, it is difficult to ensure that trainees who operate solely on the basis of explicit procedures do not evolve their own explanations of how the
system works and thus, they may acquire some sort of system prototypes. Bainbridge (1978) who examined verbal protocols of experienced operators, has found that operators kept 'mental track' of the internal state of the process, and that at shift takeover, they took some time to build such a 'mental model' of the process. In systems with complex interconnections of parts that cannot be observed by the operator, a system prototype may serve as a basis for inferring the state of 'hidden' parameters, necessary to develop a 'mental picture' of the internal state of the process.

It appears then that, when the level of abstraction and degree of task relevance are properly adjusted, system prototypes can make certain contributions to the transfer of learning. Transfer of system prototypes does not lend itself to straightforward explanations. Apparent transfer of system prototypes can also be explained by a 'common task elements' argument. The main use for exploring similar prototypes is as an expedient during training to schedule instruction to take advantage of common material.

IMPLICATIONS OF THE LEARNING MODEL FOR INSTRUCTION

The above learning model makes six implications for instructional design:

- helping the trainee by reducing the GRS distance;
- helping the trainee cope with a given distance;
- aiding the transfer of common task elements;
- aiding the process of nonspecific transfer;
- suggesting hypotheses for training 'experts'; and finally,
- modelling performance for trainability and maintainability.

Helping the trainee by reducing the GRS distance

If the task is too difficult to master, there are two ways to reduce the 'Goal-Response Set Distance' in order to make it easier for the trainee. First, we can present the trainee with a set of intermediate level goals to master, using the same interfacing operations e.g. operate pumps and valves via a control panel. When trainees have mastered these intermediate goals, the distance between the main goal and the responses now in their repertoire may be learned more easily.
For instance, mastering the goal of 'start-up a distillation column' in terms of interfacing operations is too difficult for most new trainees; we can reduce the GRS distance by setting intermediate goals such as 'establish level in column' or 'establish pressure profile', which may be achievable in terms of interfacing operations.

The alternative part-task training is to provide trainees with a set of intermediate goals as response facilities with which to execute the overall goal, rather than require them immediately to respond with the interfacing responses they must use in the real plant. In the distillation column example, we might require trainees to 'start-up the plant' using operations such as 'establish level in column', 'establish pressure profile' etc. As the overall task is learned in these terms, then the intermediate goals are themselves expanded, eventually to enable mastery of the whole task in terms of the interfacing responses. An example of such an approach is illustrated in Shepherd and Duncan (1980).

Helping the trainee cope with a given distance

In both the above cases we are simplifying the problem of response construction for the trainee. We can also help by using a training strategy to supply the trainee with appropriate knowledge to aid response construction. A common approach placing little demand upon the trainee, is by direct prompting. A less direct method is to supply him with rules and operating principles from which procedures can be generated to deal with a range of problems. Even less specific methods furnish the trainee with appropriate accounts of the process physics and chemistry. Less direct methods are assumed to be more generalisable, enabling more versatile operating skills and providing useful exercise for response construction skills.

An illustration of this form of response construction is given in a study by Shepherd et al. (1977). An experimental subject who had been taught plant theory was asked to describe how he had established a plan for diagnosing condenser failures. Through practice at the task, he had recognised that a particular pattern of column-pressure and drum-level was always consistent with this type of fault. This knowledge of plant theory had helped him rationalise why this was so. Without the theory, one suspects, the significance of the patterns would not have been so apparent, and the response would not have been constructed. It is also possible that skills arising from application
of more general knowledge are better remembered, because they entail more activity at the time of encoding than do skills arising from direct guidance.

Aiding the transfer of common task elements

The above types of instruction - that is, prompting, guidance and teaching of plant theory, can also support transfer of task elements. It will be recalled that, a number of factors such as activity at encoding, knowledge of results and form of accompanying knowledge presented, will influence the ease with which task elements are retrieved, recognised as being similar, and become adapted to new contexts. A psychological mechanism which can partially account for these effects, can be the development of system prototypes and planning elements which interact in certain ways with acquired task elements and enhance their degree of transfer. Each of these relationships will be considered in more detail below, in order to understand the way that development of a constituent response item supports learning of another.

Optimising transfer of task elements with the use of system prototypes

We can assume that each task element is associated with a system prototype at an appropriate level of abstraction. For instance, when an experienced operator uses a set of intermediate goals such as 'establish level in column', 'establish evaporation and condensation', and 'establish level in drum' as response facilities to achieve the main goal, he conceptualises the system as consisting of a number of related sub-systems such as the column, the heating system, the cooling system and the drum. Taking into account these relationships, the operator can try out alternative methods of performing the whole task, until an effective plan is constructed. The process of learning an effective plan can be accompanied by a process of refining what has already been known of these relationships; in this way, more elaborate system prototypes can be acquired, which can support retrieval and preview of plans on later occasions, so that they can be adapted for a similar context of application.

If system prototypes can optimise transfer of task elements, an important implication for training issues would be how to assist trainees develop such prototypes. A study by Patrick and Haines (1988) has shown that when certain forms of prompts and guidance are offered how to apply plant-theory to fault-
diagnosis, trainees can evolve their own diagnostic procedures which can transfer to new contexts to a greater extent than those explicitly offered to other trainees.

*Optimising transfer of task elements with the use of planning elements*

Although system prototypes may reveal functional relationships between subsystems, they do not imply a specific course of action to explore systematically these relationships. A significant amount of planning may be required to develop the most effective plan to achieve a set goal. From observations of subjects operating the simulated 'distillation column', it was found that the same goal of 'establishing level in column' could be achieved by three different plans, all of them stemming from the same 'level'-prototype. Different levels of expertise and different learning styles can result in a number of plans, all compatible with a system prototype.

The most efficient plan, in the previous example, was achieved by trainees who developed some sort of planning elements to cope with the interactions between the two sub-goals of 'adjusting the level' while 'maintaining the feedflow constant'. It is conceivable that the process of trying out alternative plans in order to fit together a set of operations, may entail a number of activities such as identifying a set of linking mechanisms between stimuli and responses, responding to relations among stimuli, receiving immediate knowledge of results, setting up standards of accurate performance etc., which can optimise transfer of the acquired plans to other contexts.

Identifying appropriate forms of information for helping this process of acquiring a set of planning elements to support transfer of existing responses is an issue for training research. A form of instruction which was thought to support transfer of task elements in the distillation example, was information about goal-interaction relationships.

*Aiding the process of nonspecific transfer*

So far, we have considered how system prototypes and planning elements can optimise transfer of common task elements. However, transfer can be observed even in situations which do not contain any explicit task elements experienced
under any circumstances. This form of nonspecific transfer can include transfer of concepts and principles (system prototypes) and transfer of strategies, reasoning styles and learning-to-learn (planning elements). This type of transfer corresponds to the process of 'response construction' (step 4, figure 5.1) where trainees face a large GRS distance. Because both forms of nonspecific transfer can reduce this distance, they will be examined in greater detail below.

Transfer of system prototypes

In chapter 2, it was shown how concepts and principles can be modelled as system prototypes and transfer either to different applications of the same domain (Travers, 1977) or to different domains (Genter and Genter, 1983; Royer and Cable, 1975). The basic mechanism of such transfer was by drawing an analogy between the 'base' (familiar) and the 'target' (new) prototypes. Holyoak (1984b) has outlined the sort of factors involved in this process of analogical transfer such as level of abstraction at which the potential base analog was initially encoded, structure preserving and structure violating differences etc. When these factors are taught to trainees, they would be expected to apply them to different applications of the same class of processes e.g. distillation columns processing different types of liquid mixtures.

Research in text-editing skills (Karat et al., 1986; Ziegler et al., 1987; Waern, 1986) has also shown that transfer can be observed between systems with similar conceptual structures (and thus, of similar system prototypes), although the syntax of commands can be substantially different.

A different form of transfer occurs, when operators with extensive experience with one particular system develop a general habit applicable to complete different systems - that is, evaluating the consequences of their actions by reducing the resolution of the system (e.g. considering any side-effects at a high-level of description) and then implementing their actions by increasing resolution (e.g. considering necessary equipment details). This is the sort of functional reasoning that Rasmussen (1986) advocates; unfortunately, there is no particular evidence of such a type of transfer, one reason being that it is difficult to isolate it from other forms of transfer.
Transfer of planning elements

Planning elements were defined as domain-specific strategies which have been the result of applying general problem solving strategies to a particular domain, in order to determine the various ways in which task elements can be stringed together in that domain. Planning elements can take the form of reasoning styles adopted by domain experts (e.g. forward vs backwards and breadth-first vs depth-first styles) as well as meta-strategies for exploring previous experience with other contexts (see previous example of exploring 'diagnostic rules' in the 'planning elements' section.

One would expect that 'variety of original learning' would be an efficient training method for supporting transfer of planning elements to other contexts. An example would be the development of what may be termed as system exploration rules to cope with the delayed feedback of various control systems. In most chemical industries, the effect of a previous manipulation does not appear rapidly and it becomes difficult to relate a result to an action, because during this interval other sources of change may have intervened. A 'rule' to explore the behaviour of such systems, is to bring the process to the target state through a series of equilibrium intermediate states where any unwarranted interventions are minimised. Indeed, delayed feedback was a major source of errors in novice subjects trying to control the simulated distillation column. It is conceivable that, when feedback can be adjusted as a training facility, operators can develop various rules to explore the system, preferably with the provision of some form of guidance. This issue is further elaborated by Crossman and Cooke (1962) who examined the types of skills required in such circumstances.

Learning-to-learn is also another form of planning elements which can operate in various contexts. One kind of such technique would be to train operators to act as experienced 'task-analysts' in their own control tasks, by analysing the whole task into subordinate operations and by making use of the proposed plan-categories. Training an operator to become a 'scientist' in his domain will have to address issues of individual differences and motivation, since it makes large cognitive demands and may take a substantial amount of time to show up its effectiveness. Nevertheless, it remains an attractive proposition to be put forward in the training research.
Suggesting hypotheses for training 'experts'

Being highly practiced at a specific range of tasks and able to carry them out reliably, may be different from being able to construct an appropriate response to unforeseen circumstances. According to the proposed learning model in figure 5.1, extensive practice of a restricted set of operating skills will lead to well compiled task elements which will be elicited rapidly as circumstances demand. But this repetitive practice will be at the expense of practising response construction and will therefore not lead to the flexible response expected by an operator. This conclusion corresponds to that reached by Anderson (1985). Both sorts of skills are required in different circumstances, so we must decide when each is required. When we cater for this kind of 'flexible' expertise, the trainee needs to master a useful set of intermediate skills, then practise them on varying goals such that the higher level goals are never actually compiled as responses in their own right.

Modelling performance for trainability and maintainability

Lastly, a point is introduced that should be considered before training even commences. Different researchers make different suggestions for training a particular type of task, for example, Shepherd et al. (1977) suggested a training regime for diagnosis training based on applying diagnostic rules-of-thumb, whereas Goodstein (1982) argued that a good basis for diagnostic skill is to explore a problem using concepts of mass and energy balance. Tested in isolation, using task simulation, both approaches might prove equally valuable. In the context of a whole task, however, we might find that one strategy transfers better to other task elements than the other; for example, the mass/energy balance ideas may also be useful when carrying out monitoring tasks, while the 'rules' approach may not. This would mean that the total regime could be easier to learn if it were based only on the mass/energy balance approach. Also, if these elements are practised more frequently on the job in dealing with one type of goal, they may help maintain skills required in less frequently occurring goals. We suggest that complete training regimes should be appraised in this way to ensure that their training will be efficient and that skills are more easily maintained during the normal course of operations. Bainbridge (1987) has warned us of the potential degradation to operator skill as more of the operator's task is allocated to artificial
intelligence. This issue deserves serious attention with the move towards automation.

CONCLUSION

This chapter has highlighted the sort of difficulties trainees may encounter in recognising task similarity relationships, and proposed a model of response learning to support design of instruction to optimise transfer. A tentative suggestion was to create learning conditions in which planning elements and system prototypes would enhance transfer of task elements. This process was distinct from the nonspecific transfer of planning elements and system prototypes to contexts which have no common task elements.

The scope of the 'Goal Response Set Distance' model of learning expands beyond the issue of transfer of learning to the training of domain 'experts' and the appraisal of training regimes against criteria of trainability and maintainability. The proposed HTA in conjunction with the model of learning will be used as a framework for designing the main experimental study and formulating hypotheses regarding the efficiency of different training methods in optimising transfer of common task elements identified in the task description of the distillation example.
CHAPTER 6

REPRESENTING AND EVALUATING PERFORMANCE OF A PLANNING TASK IN A MICROCOMPUTER: THE CASE OF THE 'CRISPS' SIMULATOR

SUMMARY

The aim of this chapter is to develop a representation of the task of 'starting-up a distillation column' in a microcomputer in order to use it as an application task for the study of transfer in the main experiment which is described in chapter 7. In order to adjust the level of task difficulty and examine any variables which may confound the effects of the training methods e.g. the display and temporal features of the simulator, a pilot study was conducted. An attempt was made to look at the extent that the 'motor' aspects of the process control task could be simulated in addition to the decision-making ones. On the basis of this information, a sample of training methods were tested and served as a basis for designing the final methods. Another aim of the pilot study was to evaluate various instructional features of the training simulator and examine the role of simulator fidelity in a learning environment.

INTRODUCTION

So far, we have considered one particular type of transfer of training, namely, 'internal' transfer between task elements in order to facilitate acquisition of the overall task. In the training situation, the original and the transfer tasks are represented in similar ways - that is, similar response facilities, display features, temporal features etc. - so that acquisition of information and thus performance, are influenced in the same manner in both tasks. In other words, task elements are simulated at the same level of task-fidelity.

Another type of transfer of training is what can be termed 'operational' transfer from the training situation to the real or operational one, in which establishment of skill is ultimately tested. There is, obviously, a reciprocal relation between 'internal-task' transfer in the training situation and
'operational' transfer in the real situation. On one hand, we need to know how best to control acquisition of a task by adjusting task-fidelity (e.g. abstract certain features of the real task and represent it in the training situation). On the other hand, we also need to examine whether the overall skill acquired in the training situation, possibly through an internal-transfer mechanism, can be carried forward to performance at the 'real' plant where it is needed.

In the context of the present thesis, 'internal-task' transfer concerns only the training situation, and examines ways to support learning of task elements so that their performance meet the task demands set in the plant simulator; 'operational' transfer manifests itself in the transfer of the overall skill of 'starting-up a distillation column' to the real plant. Since access to a real plant could not be gained, the former type of transfer will be the focus of this thesis.

ADJUSTING TASK FIDELITY TO INCREASE TRAINING EFFECTIVENESS

In general, a number of system and learning variables point out the need for simulation training in process control industries (e.g. Stammers, 1979). Simulation training is justified because some tasks are critical or the context in which they occur is dangerous or stressful. Added to these reasons can be considerations of cost effectiveness. For example, operations such as start-up or shutdown of a plant cannot be tolerated solely for training purposes.

Apart from these 'system' reasons, a consideration of important learning variables will show the need for a controlled learning environment. Control procedures which support learning such as guidance, prompting, and feedback, can prevent or minimise errors. Trainees' interaction with the task can also be controlled by adjusting the degree of task complexity and some temporal characteristics of the simulated plant. For instance, trainees can be given a simple task to begin with, e.g. various parts of the overall task, or a general outline of the system before they practise the whole task; on the other hand, practice on a simulator can allow slowing-down or speeding-up of the task in order to enable response sequences to be learned.
However, deliberate manipulation of these features in order to increase training effectiveness, may jeopardise transfer to the real situation. Shepherd (1977) who discussed the issue of training 'control panel diagnosis' from static displays, has cautioned us against two potential side-effects of reduced task-fidelity. A simulation can limit the range of strategies available to trainees, but any of this range may transfer positively to the real situation; for instance, providing a static simulation rather than temporal build-up of the symptom pattern, will prevent trainees developing a strategy involving rates of change of symptoms. A second result of adjusting fidelity is that it may permit the acquisition of non-transferable strategies which may have little value beyond the training situation; for instance, trainees may distinguish faults by identifying visual patterns which, in the real situation, may only be displayed for a period too brief for them to complete the diagnosis.

We need, therefore, some guidelines how to adjust task-fidelity in order to enable acquisition of a substantial number of strategies, all of which should transfer to the real situation. Ideally, such guidelines should be tested by properly designed transfer studies. Duncan and Shepherd (1975), however, have argued that such studies might be impractical due to the same reasons for simulating these tasks during training e.g. infrequent occurrence of start-up and diagnostic operations, large sample of required operators etc. Given that transfer studies are ruled out, two alternative approaches have been suggested: techniques to identify critical features examined by task 'experts', and lists of dimensions of fidelity which affect performance of the task.

Identifying critical features examined by operators

Shepherd (1977) has reported three techniques for identifying operator strategy, namely, eye movements, blanking off parts of the display and verbal protocols. Measuring eye movements cannot be used as a reliable source of information, since it says nothing about how operators encode and use information. The other two techniques can give better representations of 'internal' events, although they cannot sufficiently justify loss of task-fidelity.

'Blanking off' parts of a display does not necessarily mean that the only items of information lost are the individual instrument readings. Operators may well respond to the pattern produced by a block of instruments, and this use of information cannot be addressed by this technique.
Verbal protocols can also bias any description of behaviour, since they require serial reporting, if not serial collection of information by the operator. They also constrain him to reporting only information that he can code verbally (Bainbridge, 1979).

Given that attempts to identify critical features used by operators are unsatisfactory, the third technique of identifying dimensions of fidelity seem to be the best way of specifying guidelines for task simulation.

**Dimensions of fidelity affecting task performance**

Several studies in the area of aviation and process control have examined the effect of certain dimensions of fidelity upon task performance. These studies have been reviewed by Stammers (1981) who proposed a list of important dimensions of fidelity, which will briefly be cited here in order to understand the complexity of the area and enable the development of an effective plant simulator. A variation of the original list suggested by Stammers (1981) can include the following five important dimensions:

(i) **Stimulus/Response features of the task.** The concern here is with the physical resemblance of displays and controls in a simulation in relation to the real situation. Important aspects of the display include its size which will determine the amount of information collected in one brief span, and its layout which will affect location and interpretation of instrument readings. Other aspects include certain dynamic characteristics that have to be learned. Input devices and their operation present fewer fidelity problems. However, it should bear in mind that what need be simulated is the type of interaction of the trainee with the controls rather than their physical characteristics. An example is given by Gagne (1962) about the 'pressure aspects' of a control stick, in the context of training cockpit procedures as opposed to motor skills; it seems obvious that, stick pressure is important only to the latter type of task interaction.

(ii) **Task complexity.** This dimension concerns the extent to which the total task complexity is put before the trainee. This could be held to be quantitative fidelity, in the sense that it specifies the number of simulated functions of an equipment or possible system states. It will be recalled that task complexity
can be reduced either by a part-task training regime or by providing trainees with intermediate-level goals as response facilities.

(iii) Temporal aspects. This dimension concerns the extent to which tasks are slowed down or speeded up; this alteration is carried out in order to enhance learning rather than to represent the real situation directly. Adjusting the time-base of a task can increase substantially training effectiveness. A good example of this approach is the 'back panel projection technique' of Duncan and Shepherd (1975) which enables the comparison of many fault conditions that are potentially confusable within a collapsed time span.

(iv) Instructional control. A number of features are built into simulators that are not there in the real task, but enable better control of the learning of a task. Some simulators enable playback of a situation, freezing of the task at a particular point in time, in addition to guidance and extrinsic feedback which have already been mentioned. Another important control aspect is 'withholding' information until it is requested by the trainee. This enables a greater control to be exercised over his strategy, and provides the basis for more detailed measurements of performance to be made. However, these features need to be faded gradually, so that performance resembles the ultimate task demands in the end of training.

(v) Stress. Simulation training is often adopted to avoid the hazards of the real situation as well as prevent the results of inadequate performance impinge on the individual. However, if such stress is a feature of real life tasks then training must prepare trainees to cope with them. The topic of stress is a controversial one, since there is no particular way of accurately simulating likely forms of stress during training. Shepherd (1977) has argued that one way to cope with stress is to provide extensive practice with task components in isolation, so that adopted strategies rely on a minimal amount of information collection, and trainees are convinced of their ability to perform successfully.

It is hoped that further research will produce a solid body of knowledge that is needed for the more effective design of simulators. These principles have been used in the design of a plant simulator of a distillation column, which is further described in the next section.
DESCRIPTION OF A COMPUTER BASED PLANT SIMULATOR

This section describes a computer based plant simulator which is based upon elementary principles of distillation. In this sense, the simulator does not model the characteristics of a particular plant but it can be adapted to model a variety of distillation plants and types of processed materials. Although the simulator is of low to moderate fidelity, it can easily be manipulated and tailored to the requirements of many experiments. In addition, because the plant is not modelled to the lowest level of detail, there is no requirement for employing experienced subjects to operate it.

The proposed CRISPS simulator (Computer Representations of Interactive Steady Phase Systems) represents an attempt to incorporate the benefits of existing simulators into one generic simulator while avoiding as many of the disadvantages as possible. CRISPS is a computerised, interactive, and steady or equilibrium-state simulator of distillation plants. It provides an opportunity for developing planning strategies for operations such as start-up, shutdown or compensation as well as for fault-diagnostic strategies by incorporating the benefits of static simulators (e.g. Shepherd et al., 1977). Because it is computerised, it provides a number of instructional facilities such as manipulation of task complexity, time-base of the system, freezing of the task, and amount of presented information. Added to this, the system can be controlled through two different display modes.

In general, computer simulation enables modelling of real processes, and thus development of high fidelity simulators. Examples include a zero-energy reactor (McLeod, 1976), distillation columns (West and Clark, 1974; Patternote and Verhagen, 1979), a melting shop (Bainbridge, 1974), a soaking pit (Ketteringham and O'Brien, 1974), and a steam production plant (Hollan et al., 1984). Some of the above mentioned simulators, such as distillation columns, employ realistic settings for the processes they model. These simulators provide high fidelity but little control over the learning environment. The purpose of the proposed CRISPS simulator is to 'buy' training effectiveness by sacrificing some aspects of fidelity. A detailed description of the simulator is presented, followed by a pilot study to evaluate the simulator as an experimental tool.
The underlying concept

The choice of a distillation plant as a research tool was based upon the following considerations. It is very difficult to generalise research findings from complex man-machine systems (e.g. electric energy plants, chemical plants) to each other. Therefore, it seems useful to start research with a widespread industrial process like distillation. Another important consideration was the accessibility to a static simulation of a distillation column developed by Shepherd et al. (1977), which described fault conditions commonly observed in real plants. Added to this, is the fact that distillation columns provide a meaningful context to model performance criteria required in most chemical plants; thus, any course of action will have to be judged against criteria such as quantity of raw material supplied, demands for finished goods, response time, consumption of energy resources, and oscillation of established parameters.

The task that the operator is given, which is of concern to this thesis, is to start-up the column and bring the process to a steady state where certain product conditions prevail. Supply and product demands are specified and assumed to be constant over a trial; thus, the bottleneck in the task is the handling of the processed liquid mixture itself. Performance can be measured in terms of time to complete the task, stability of operation and cost of operation (mainly energy consumption).

System architecture

The software of the CRISPS simulator is written in Prospero Pascal and is running under Nimbus PC terminals. It occupies approximately 100 Mbytes or 5000 lines and it can be transported in a floppy disk. The simulator consists of two modules, that is, a graphics module and a mathematical model of the plant. As it can be seen from figure 6.1, the operator interfaces the system through the graphics module which is continually updated by the plant model. The system performs the following functions: initialise (1), select options from menu (2), accept trainee's response and update plant-model (4), run the plant-model (5), update display parameters (7), calculate performance criteria (3), and store data (8).
FIGURE 6.1. Control of the plant simulator.
The response facilities provided by the simulator are adjustments of pumps and valves which affect various flows. For simplicity, all valves are of the same type and they can be adjusted to take any value from 0 to 99, which corresponds to the percentage of the cross-sectional area of the pipelines which is left open for liquid circulation. Pumps can be either closed or open (either 0 or 1), however, they are of different capacity or size which is not adjustable over a single trial. Therefore, the rate of flow is proportional to the valve position and the size of the actuated pump. Plant operation resembles a problem solving situation in which the operator has to find out an array with the optimal valve-positions that brings the process to the required product specifications.

When the plant is updated, the mathematical model runs through all the chemical equations to calculate the future state of the process, an operation which will be referred to as the production run of the simulator and which takes approximately three seconds. Because the hardware is serially operated, the plant 'freezes' every time the operator performs a control action; this is in contrast to the real situation, where the plant is operating uninterrupted from the operator's actions. As a result, the overall time to perform a task includes the time spent to update the plant in addition to the time taken for the actual operation of the plant. One way to keep the time to update the plant to a minimum, is to require operators to do all their 'thinking' when the plant is running rather than when the plant is 'frozen' for an intervention. Speed of performance can be measured in terms of time to complete the task as well as the number of production runs used in a single trial.

Every time the operator wants to intervene, he has first to press the <return> key, then change the valve positions, and finally type 'run' in order to continue his task. Thus, a number of instructional features can be provided such as 'freezing' the present state of the process, and controlling the task in a 'self-paced' manner. It is conceivable that stress due to 'hands-on' control with a complex task in the initial stage of learning can also be reduced.

System response

The CRISPS simulator cannot capture the dynamics of a real plant, however, it is an interactive simulator, since it responds to the operator's control actions. This is done with the mathematical model which calculates the final
(t \to \infty) \) values of the output specifications as a function of the current setpoint values; thus, only the equilibrium or steady phase values of the process parameters are calculated. Although the lags are not faithfully represented, the operator can get a good estimate of the cause-effect relationships and of the size of effects (gains); the system is said to have a pure-gain response.

Most chemical processes, however, have either first or second order responses, which can approximate the response of the CRISPS simulator in the cases where only gradual adjustments of the valves are made. Another way would be to increase the time to complete a production run, by delaying its execution for some more seconds. A good example to illustrate the first point, is the response of the temperature of a water bath in a study by Attwood (1974). Figure 6.2 shows that small step changes of the heater setting (route-2) result in pure-gain response of the temperature; while, large step changes (route-1) make the response slow.

In order to compare the response of the previous laboratory task with the one of the CRISPS simulator, the performance of a subject in Attwood's study was compared to a hypothetical performance of the same subject on the CRISPS simulator. Figure 6.3 shows the initial temperature-overshooting (control route Ca) typical in the operation of a 'real' system, as opposed to the simple step change (control route Cb) required in operating CRISPS; on the other hand, the gradual 'building-up' of the temperature (response route Ra) can be compared to the pure-gain response of CRISPS (response route Rb). However, from the same figure it can be seen that, the CRISPS simulator can capture cause-effect relationships as well as gains, because it demonstrates how an increase of the setting of 25 units (60 minus 35) can cause an increase of the temperature of 15°C (55°C minus 40°C). Unfortunately, the precise response route (Ra) of the temperature cannot be represented, unless subjects are instructed to make small control changes only.

It seems then, that CRISPS can mainly capture the decision-making aspect of process control tasks, but it is not suitable for practising motor skills. There are two ways to make the operation of the simulator resemble that of a real
Figure 6.2. The effect of size of step-changes upon system response, in a study by Attwood (1974).

Figure 6.3. A comparison of the simulator with a real system.
plant: (i) require subjects to update the plant in small step changes, and (ii) adjust the 'execution time' of a production run.

In most chemical plants, however, motor skills are taken out of the hands of the operator and are assigned to the automatic controllers, making the decision-aspects of the task more important contributors to the overall performance. Therefore, CRISPS can be an invaluable tool for practising modern process control tasks. In fact, Patternote and Verhagen (1979) have reported that a similar interactive software was used as an advisory model for control engineers and production staff, at the DSM chemical industries in the southern part of the Netherlands. This 'static' software could be utilised as a 'predictive display' in order to predict the required target values of various control settings and achieve certain product qualities. A number of studies (Brigham and Laios, 1975; Shackel, 1976; Smith and Crabtree, 1975; Sheridan, 1981) have demonstrated that 'predictive displays' can help operators to cope with an important planning component, namely, the prediction and anticipation of future system states.

The CRISPS simulator can be used as a 'predictive display', when the execution time of a production run is adjusted to the minimum of 3 seconds and trainees are not constrained with respect to the size of valve adjustments. On the other hand, during the usual operation of the plant, the process can become as 'sluggish' as we wish by increasing the execution time of a production run and by constraining subjects to make small valve adjustments only.

An important question then remains, how trainees can practise the motor components of process control tasks in cases where these are required in the real situation. One solution could be to develop high fidelity simulators which model only some parts of the task that heavily rely on motor skills; with a part-task training regime, the operators can learn how to integrate the motor and decision components of the task.

System options

The simulator offers a number of options, specified in the master menu which appears upon entering the system. These options were judged to be very important in providing control over learning. There are five facilities which have already been built in the current version of CRISPS and enable adjustment
of the time-base, the size of the plant and type of processed liquid, the kind of feedback, the type of data analysis, and finally, the type of display.

**Time base.** We have already discussed the possibility of adjusting the execution time of the production run.

**Size of plant and type of processed liquid.** It will be recalled that, the aim of this simulator was to model a range of distillation plants with different sizes and types of processed liquids rather than the specific dynamics of a particular plant. This can allow us to measure transfer to a variety of different contexts of application.

**System feedback.** Another facility concerns the amount of feedback that the operator receives regarding the number of process control parameters that he is allowed to monitor. It is possible to 'blank-off' certain parameters of the display and examine the types of critical information required by experienced trainees. Although this approach has certain limitations, it still remains an option.

**'On-line' data analysis and storage.** Because CRISPS is a computer based simulator, it can calculate a number of performance measures such as number of production runs used, energy consumption, and control performance. In addition, a record is made of all 'process state - control action' pairs, in order to assist in the qualitative analysis of the operator's strategy.

**Display modes.** Finally, the simulator provides two different display modes through which the plant can be operated. The conventional display (figure 6.4) mimics the conventional control panel which consists of various instruments such as indicators (e.g. PI5), meters (e.g. FR1), recorders (e.g. LR1, FR11, FR3), and indicator-controllers (e.g. LIC1, LIC11); the other mode is the product-flow display, which is representative of modern computer-based VDU displays and shows the flow of the product on a plant diagram as well as numeric values of process parameters (figure 6.5).

The conventional display incorporates a plant diagram in order to assist trainees in identifying various instruments relatively easily as well as in understanding possible relationships between these. This type of display was found by Reiersen (1985) to improve diagnostic strategies compared to another display in which instruments were randomly displayed. In addition, the conventional
display can encourage people to exploit various spatial relationships between process parameters and develop 'pattern-recognition' strategies.

The product-flow display enables larger parts of the system to be represented, which may assist trainees in capturing the 'overall picture' of the internal state of the plant. However, since the simulated distillation column does not occupy a great deal of space, this display mode represents the same number of equipment with those on the conventional display.

Certain types of equipment were coded in different colours in order to enable trainees to locate them easily. For instance, the pipelines which carry the product are in 'green', whilst those that carry the heating and cooling agents are in 'red' in order to distinguish them as having to do with energy consumption; all other equipment is coded in 'blue'. In addition, all the current values of parameters are in 'green', whilst the target ones are in 'blue'. The 'pros' and 'cons' of each display mode have been examined in the pilot study which follows and are discussed below.

Instructional facilities

In brief, CRISPS has three main characteristics which make it an effective environment for learning, namely: (i) it is a steady or equilibrium phase simulator and aims at modelling a range of different plant sizes and types of liquid mixtures; (ii) it is 'interactive' because it has a mathematical model build in it; and (iii) its time-base is adjustable.

Because of these features, we can exert control over the following learning events: the simulator can be used as either a real plant or a 'predictive' display; the task can be controlled in a self-paced manner when trainees are allowed to 'freeze' the plant as long as they wish; although temporal fidelity is low, it can be adjusted so that certain parts of the task can be speeded up or slowed down, and potentially confusable faulty states can quickly be retrieved and compared; better transfer measures can be developed by examining performance in a variety of different plants; and finally, it can be used to explore different operational procedures and identify the most optimal ones.
Figure 6.4. The conventional display of the simulator, which was used in the main experimental study.
Figure 6.5. The product-flow display of the simulator.
Table 9.1.

Control actions of subject S1 of the procedures-group at the original task.

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<th>Goals</th>
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<tr>
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<tr>
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<td>25 54 85 85 60 99</td>
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Figure 6.4. The conventional display of the simulator, which was used in the main experimental study.
Figure 6.5. The product-flow display of the simulator.
A number of other facilities, commonly encountered in many commercial simulations, were also built on CRISPS such as two display modes, adjustment of the number of parameters presented, and storage facilities in order to make it an 'easy-to-use' instructional tool. All of these advantages are offered at a very low cost, since the only hardware requirements is a personal computer and the software is quite simple. In order to adjust the level of difficulty of various tasks and exploit the way that these facilities could better be used, a pilot study was set up.

A PILOT STUDY TO EVALUATE PERFORMANCE ON THE SIMULATOR

A pilot study was carried out in order to identify features of the simulator which could influence performance, to adjust the level of task difficulty, and to examine the effectiveness of various types of training information such as procedures, theory of the plant, and explanations. The study employed six subjects in total. Three of them were students in chemistry and chemical engineering and they formed the 'task analysis' group which evaluated the simulator and provided technical information to the experimenter who did the HTA of the start-up of the plant in chapter 3. The other three subjects had no prior knowledge of the distillation process, and were employed in order to test the three previous methods. The performance of this group, which will be called the 'training analysis' group from now on, was compared to the unaided performance of the more experienced subjects of the 'task analysis' group. A more detailed discussion is to be found in the following sections.

Adjusting the level of task difficulty on the simulator

The following features of the simulator were manipulated in order to adjust the level of task difficulty.

The effect of display mode

The product-flow display (Figure 6.5) was found to be easier to use in the initial stage of learning, because the plant diagram helped subjects to understand the relationships between parameters, and because displayed information concerned only the current and target values of each parameter. With the increase of
practice, the *conventional display* proved to be more useful, because it contained more information about each parameter, and this provided a better basis for making decisions. Three types of information could be received from different instruments on the conventional display, that is: numerical values (meters), bar-graphs relating current and target values (indicators and controllers) and trends of parameters (recorders). The bar-graphs enabled subjects to monitor quickly how close to the target a parameter was, without the need to read the numerical values of the current and target values; on the other hand, the recorders enabled them to identify the size of any changes, without the need to remember the precise value of previous readings. Since the subjects had to control the plant manually, the indicator-controllers were used as indicators, merely proving redundant information about the current valve-position in terms of a horizontal bar-graph. On the basis of these observations, it was decided that the *product-flow display* should be used only for demonstrations, while the main task would be carried out on the *conventional display*.

**The effect of size of valve-adjustments**

It will be recalled that small step changes made the behaviour of the plant resemble the one of a real plant, and this made the task very difficult. On the other hand, when subjects were at liberty to adjust valves in large steps, the task became increasingly easy which made the efficiency of different strategies difficult to estimate. After many trials, it was felt that valves should not be adjusted in steps greater than 30 units per intervention.

**The effect of target-tolerances**

When subjects were required to achieve a target parameter to a stringent criterion e.g. 'level in column absolutely stable at 30 cm', the task became quite difficult but it provided a good basis to judge how effective a strategy was. On the other hand, some subjects found the task quite 'boring', since once the level approached the target and remained stable, additional effort was required to fix it on the target value. It was necessary then, to decide the tolerances of all parameters so that the task was challenging enough, yet not 'boring'. It was felt that the levels in the column and drum should be kept steady within a tolerance of ± 3 cm from the target value.
The effect of instrument location

It will be recalled from chapter 4 that, the location of the recorder of the quality of the top product (Xd) made the task of estimating the true value of Xd difficult. When the value of Xd in the condenser was displayed in addition to the average value of Xd in the drum, the task of establishing the first stage in distillation became easier. However, it was decided not to present this additional information, and make greater demands in terms of a strategy to cope with this situation.

The effect of size of column

Another interesting finding was that, when the size of the column was increased, the task became very difficult for the subjects who did not seem to appreciate the fact that even a small increase in pressure would mean a large amount of vapour inside the column, and thus, a great amount of time to recover it; when the size was reduced, the pressure became more responsive, that is, it was easier to increase the pressure and equally easy to recover it. Again an 'optimal' size had to be found. The same sort of arrangements were made for the response time of the level in the column and drum.

The effect of the time-base

Finally, the time-base was found to have an effect on both motivation and types of strategies adopted by subjects. Specifically, when the time-base was adjusted to the minimum of 3 seconds, the task appeared to be very stressful as it became very difficult to control the plant; the typical response of the subjects was to press the <return> key very frequently in order to freeze the plant. That, of course, created some problems for an accurate measure of speed of performance. On the other hand, when the time-base was adjusted to 20 secs, the process became very slow and made subjects anxious for the next production run or intervention.

The problem appeared to be very complicated because the time-base had an effect upon their strategies as well. Specifically, the slower the response of the plant the lesser the feedback given on a parameter, the greater the demand for predicting the precise size of effects. This finding is in accord with many process control studies (Crossman and Cooke, 1962; Attwood, 1974), that is, the
slower the system response the greater the demand for a feed-forward or open-loop strategy.

In consideration of these problems, the time-base was adjusted to 10 seconds. However, the time-base proved to have also a very important effect upon the way that subjects would use different types of training information, and this issue is separately discussed in the next section.

Exploring the effectiveness of various training methods

An important aim of the pilot study was to examine what types of training information and at what level of description, would enable subjects to acquire the skill of establishing the first stage in distillation and subsequently transfer to the final stage. To this extent, three training methods were examined, namely: (i) 'procedures' to perform the original task; (ii) 'theory' of the functioning of the plant; and (iii) a combination of 'procedures' and 'explanations'. At this stage, it was not clear what type of plant-theory would enable subjects to evolve their own operational procedures nor was the nature of 'explanations' for the third method clear. The three novice subjects of the 'training analysis' group participated at this phase of the pilot study.

At this stage, it is premature to speculate on the precise advantages of each method, however, an important finding was the interaction between type of instruction and the use of the simulator as a 'predictive' display. It will be recalled that, when the time-base was set at low values and there was no constraint on the size of valve-adjustment, the simulator could function in a 'predictive' mode. As a result, subjects could try out alternative plans and evolve their own 'procedures' to achieve various goals; on the other hand, subjects could learn more about 'how-the-system-works' and refine their knowledge about the process. In fact, this is what has happened to a large extent in the pilot study; it was very difficult to separate the effects of type of instruction from the ones produced by this use of the simulator in a predictive mode.

When subjects were constrained to use the simulator as a 'real' plant, performance differences emerged. It was apparent that the effects of type of instruction were confounded with the use of the simulator in a 'predictive' mode, and this had important implications for the design of the main study.
A decision was reached that this facility would not be available, with the exception of the 'theory'-group during the first two days of their training, in order to demonstrate the application of plant theory.

A tentative conclusion of the pilot study was that the subject who was given 'procedures' had a lot of difficulties with the transfer task, although the procedures were effective for both tasks. The other subject who was provided with plant theory, although he evolved less-optimal plans than the 'procedures', he was in a better position to apply those in the transfer situation. The third subject appeared to perform a bit better than the others, however, it was not easy to estimate these differences accurately.

In general, the findings of the pilot study were very useful because they indicated various ways to adjust the task difficulty, and they revealed a potential factor which could confound the effects of the training methods. When the time base was adjusted at 10 seconds, this confounding effect appeared to be minimum.

CONCLUSION

From the previous discussion, it appears that the study of 'internal' transfer of task elements raises the issue of adjusting the conditions under which the original task is acquired. If the original task can better be acquired by adjusting task fidelity in the learning situation, then an important question is raised about the degree that trainees will perform the original task equally well under more realistic conditions set on the CRISPS simulator. This issue of the relationship between task fidelity and learning has been addressed to a limited extent in the pilot study, because all the tasks in the main experimental study will be represented at the same level of fidelity.

The proposed CRISPS simulator has three main characteristics, namely: it simulates a variety of distillation plants to moderate fidelity rather than the precise dynamics of a particular plant; it is interactive, because it incorporates a mathematical model; and, finally, it can be used either as a 'real' plant or as a 'predictive' display by adjusting its time-base and size of control actions.
A pilot study has shown that the CRISPS simulator constitutes an effective learning environment. An important finding was that the use of the simulator as a 'predictive' display would confound any effects due to different training methods. The difficulty of the task was also adjusted in order to create challenging tasks to be learned, yet not very difficult.
CHAPTER 7

AN EXPERIMENTAL METHODOLOGY TO INVESTIGATE TRANSFER OF TRAINING IN A PLANNING TASK

SUMMARY

This chapter describes an experimental study which was set up in order to investigate the effectiveness of four training methods upon the transfer of 'common' task elements. Based upon the proposed model of response learning, three hypotheses were formulated with respect to the performance of the four groups at the original and transfer tasks as well as practice effects on transfer. Although an attempt was made to control for nonspecific transfer, because of the complexity and flexibility entailed in the performance of process control tasks some degree of nonspecific transfer was expected to occur. To this extent, another two hypotheses were set regarding the development of planning elements and system prototypes.

INTRODUCTION

In previous chapters, it has been shown how complex cognitive tasks can be redescribed into a hierarchy of intermediate goals, and how a proposed taxonomy of plans can be used to identify goals sharing common task elements. Illustrating this approach, the overall task of 'starting-up a distillation plant' was broken down into two stages each having three different intermediate goals in common. It was also pointed out, that although we may assume positive transfer between different goals, the amount or size of transfer will rest with the trainee recognising these goals as being of a similar kind. This, in turn, will depend upon the way that acquired responses for these goals are encoded and stored in the trainee's repertoire. Different forms of instruction may support transfer of task elements, because they may bring into play a number of influencing factors such as activity at encoding, knowledge of results, linking mechanisms between stimuli and responses etc.
The effect of the form of instruction upon transfer of task elements, is a major research question addressed in this thesis. The 'Goal Response Set Distance' model of learning will be used as a basis for designing forms of instruction to optimise transfer of task elements. Another research question concerns the issue of nonspecific transfer and the development of planning elements and system prototypes in groups which have not been provided with these response items in the original learning situation.

THE EFFECT OF FORM OF INSTRUCTION UPON TRANSFER OF TASK ELEMENTS: A COMPARISON OF FOUR TRAINING METHODS

The 'Goal Response Set Distance' model of learning, although not corresponding to the complexity of human behaviour, constitutes a good basis for training design. Fundamental cognitive processes outlined in the learning model include: a search in one's response repertoire for suitable task elements acquired in other contexts; a process of response construction when such elements do not match the current context; monitoring and evaluation of performance; and finally, storage of constructed response for future use. The response repertoire was conceptualised as consisting of three items, namely: task elements, planning elements, and system prototypes which are assumed to interact in certain ways; it might be the case then, that acquisition of one response-item may support learning of another.

A major suggestion, in chapter 5, was that transfer of task elements can be optimised when trainees are equipped with additional planning elements or system prototypes which can help them retrieve and modify previously acquired task elements to new contexts. One source of difficulty in process control tasks is their nature as very flexible tasks, allowing trainees to develop different responses equally effective for the same task. However, the amount of transfer will depend upon trainees recognising which of the existing responses are the most effective ones for a new context; this is a difficult decision, since a sub-optimal, but still acceptable response may be chosen. It is mainly in these situations that the support of planning elements or system prototypes should be appreciated.
The four experimental groups

The above transfer mechanisms can be supported by various training methods such as teaching of plant-theory, goal-analysis of a task, exploration of an interactive environment etc. Four different types of training methods will be investigated for their potential to optimise transfer of task elements, namely:

(i) provision of procedures;
(ii) procedures and additional analysis of goal-relationships;
(iii) teaching of a structural model of the plant; and,
(iv) practice on a simulated plant.

The groups were trained 'how to achieve the intermediate stage in distillation' and subsequently, were transferred to the task of 'achieving the final stage of distillation, from an established intermediate stage'. Both the original and the transfer task were performed on the CRISPS simulator, using the conventional display. It will be recalled from chapter 4, that the two stages in distillation have three different intermediate goals in common, namely, 'adjust level-1 in the column', 'establish product qualities', and 'adjust level-11 in the drum'. Although, this can be ascertained from the HTA of the overall task, the degree that trainees will perceive them as 'common' will depend upon the type of training information provided. A brief description of the training information given to each group is presented, followed by a set of hypotheses concerning the size of transfer for each group.

The procedures-group

The first group of subjects was given a complete description of the operations and plans involved in performing the original task as well as a list of procedures or plans to achieve each of the three intermediate goals and organise them in the context of the intermediate stage of distillation. Figure 7.1 displays the task description given to the 'procedures-group', and it includes all operations and plans described in the HTA in figures 4.3 and 4.4. The list of procedures to perform the task is shown in table 7.1.
Figure 7.1. Task description for the procedures and analysis groups.
Table 7.1. Instructions given to the procedures-group.

<table>
<thead>
<tr>
<th>OP-A:</th>
<th>Set Intermediate stage of distillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN A:</td>
<td>Do operation 1, then 2, then 3.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-1:</th>
<th>Establish feedflow at 1.9 kg/sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-1:</td>
<td>Increase value of valve Vi, until feedflow equals 1.9 kg/sec; then log value of Vi corresponding to target flow.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2:</th>
<th>Establish product qualities at 21% (bottom one) and 50% (top one), maintaining level-1 in column at 30 cm (±2);</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-2:</td>
<td>Do operation 2.1, then 2.2.</td>
</tr>
<tr>
<td>OP-3:</td>
<td>Establish level-11 in drum at 15 (±2).</td>
</tr>
<tr>
<td>PLAN-3:</td>
<td>Do operations 3.1 and 3.2 in sequence.</td>
</tr>
<tr>
<td></td>
<td>- Carry out operation 3.1 by increasing Vd, and then log value of Vd corresponding to a steady level.</td>
</tr>
<tr>
<td></td>
<td>- Carry out operation 3.2 by adjusting Vd to achieve target level and then return Vd to its logged value.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2.1:</th>
<th>Adjust level-1 in column at 30 cm (±2), until it becomes relatively steady.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-2.1:</td>
<td>In order to adjust level-1 in column, follow steps below:</td>
</tr>
<tr>
<td></td>
<td>- increase level-1 above 20 cm, by increasing Vi above the logged value;</td>
</tr>
<tr>
<td></td>
<td>- keep level steady at any position, by returning Vi to logged value and by increasing Vo; then log value Vo corresponding to target level;</td>
</tr>
<tr>
<td></td>
<td>- tune level-1 to be on target and maintain it steady, by returning Vi and Vo to their logged values.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2.2:</th>
<th>Establish product qualities at 21% (bottom product) and 50 % (top product) approximately. Provided that evaporation is 'partial' and condensation is 'complete', any increase in heat supply will have the following effects: (i) the amount of top product will increase, whilst the amount of bottom product will decrease; (ii) the concentration in the more volatile component, will decrease in both products.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-2.2:</td>
<td>Do main operation 2.2.1 and whenever possible do 2.2.2 at close time proximity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2.2.1:</th>
<th>Establish evaporation and condensation, minimising energy consumption.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-2.2.1:</td>
<td>Do operations 2.1.2.1 and 2.1.2.2 together. For the range of operating conditions in this trial, this can be best achieved by setting the two flows at equal values.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2.2.2:</th>
<th>Flush out level-11 in drum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN-2.2.2:</td>
<td>Adjust value of Vd to maximum, every time level-11 is above 5cm.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP-2.2.1.1:</th>
<th>Adjust evaporation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN 2.2.1.1:</td>
<td>Keep the rate of flow-2 constant, and increase the rate of heating flow gradually, so as not to consume a lot of energy.</td>
</tr>
<tr>
<td>OP-2.2.1.2:</td>
<td>Adjust condensation, maintaining pressure profile less than 1.5 at.</td>
</tr>
<tr>
<td>PLAN-2.2.1.2:</td>
<td>Either increase the rate of cooling flow or decrease rate of heating flow, taking care not to disturb product qualities.</td>
</tr>
</tbody>
</table>
In general, 'procedures' are assumed to be very effective plans for executing a task, and thus, they may leave little scope for experimenting with the task and evolving one's own responses. One would expect that trainees are not 'actively' engaged in learning these 'procedures, and that any chance to encounter any sort of 'risky' process conditions is kept to a minimum. As a result, trainees may not be able to recognise or modify these in a new context, and this will affect the amount of transfer observed.

Although, a number of studies in process control (e.g. Shepherd et al., 1977; Morris and Rouse, 1985) have shown that 'procedures' is a very effective method of mastering a task, there is not enough evidence that they can also support a high degree of transfer to new situations. In the context of transfer of text-editing skills, a number of studies (e.g. Ziegler et al., 1987; Karat et al., 1986; Pollock, 1988) have shown that 'procedures' do transfer to new situations; however, the amount of transfer will depend upon additional forms of instructions given either before or after the acquisition of the original task.

In order to be consistent with the view that 'procedures' should increase speed and accuracy of performance, some of the 'decision plans' in figure 4.4 were modified to either fixed sequences (e.g. plan-2.1) or remedial cycles (e.g. plan-2.2.1.1) in figure 7.1; the plan-2.2.1.2 was left as a 'decision' plan since it did not present great difficulties. In addition, plan-3 for adjusting the level in the drum was specified as a fixed-sequence plan (figure 7.1), instead of a remedial-cycle plan (figure 4.4) which appeared to be relatively more time-consuming.

The analysis-group

The second group of subjects was also supplied with the same list of procedures, and received additional explanations about the goal-relationships in the task description. Goal-relationships constitutes a form of planning elements, which may enable subjects to understand the reasons why the prescribed procedure is the best approach to perform a particular task as well as the conditions which may render some of the procedures sub-optimal. An empirical question is the extent that acquisition of these additional planning elements will enhance transfer of existing procedures to new contexts. The sorts of planning elements provided to the 'analysis-group' are described in figure 7.2.
Establishing feedflow overlaps with Goal-1 ($V_i$ in common):
When stabilising the level in column, adjust $V_o$ while maintaining $V_i$ constant in the position corresponding to the target feedflow.

Goal-1 overlaps with Goal-2 ($V_o$ in common):
Whenever the quality of the bottom product is re-adjusted, maintain $V_o$ constant so as not to disturb established level-1.

Goal-2 overlaps with Goal-3 ($V_d$ in common):
Because level-11 in drum may prevent you from estimating the real composition of the top product, adjust $V_d$ in the maximum position to flush out level-11. When quality of top product is approximated, adjust $V_d$ as you wish in order to keep level-11 steady.

Goal-3 overlaps with Goal-1 ($V_r$ in common):
When $V_r$ is adjusted as part of the final stage in distillation, all goals will be disturbed since another input is added to the level in column.

Figure 7.2. Analysis of goal relationships provided to the analysis-group.
From the same figure, it can be seen that the 'procedures' were grouped under three main sub-goals which can provide a meaningful context for assimilating them.

However, if rapid acquisition of a task is the primary training objective, as opposed to transfer, additional provision of planning elements may not increase speed and accuracy of performance, since procedures may themselves be very effective for the range of operating conditions they were designed to work. In fact, a study by Morris and Rouse (1985) found that provision of principles of operation in addition to procedures, did not enable subjects to perform better than those provided only with procedures. When training allows subjects to practise procedures in a class of situations, they may come to learn the underlying 'principles of operation' merely by trying out modifications of these procedures. This seems to have happened in the study of Morris and Rouse where 'variety of training' may well have normalised any differences between these two groups.

On the other hand, if the emphasis of training is put on transfer to situations not previously been encountered during the normal operation of the process, operators may have difficulties in fitting existing procedures to new orders, without the support of planning elements. In order to ensure that subjects of the analysis-group had actually assimilated the taught planning elements, they were given some exercises beyond the actual task such as planning how to cope with an increase in feed supply or demand for better product qualities without disturbing established parameters.

Finally, all procedures were justified in the context of the provided planning elements. In order to encourage subjects to be engaged in some sort of 'active' learning, they were told to find for themselves how to time-share operations 2.2.1.1 and 2.2.1.2; thus, subjects had to find a 'safety' ratio between rates of heating and cooling flows, so that all vapour produced in the column would be condensed completely.

The model-group

The third group of subjects was given a qualitative model of the structural and functional relationships of the physical components of the plant, and they were
left alone to evolve their own procedures to achieve the intermediate stage of distillation. The model of the plant emphasized the idea that the whole plant could be conceptualised as consisting of a number of interacting sub-systems namely, the reboiler, the column, and the condenser; each sub-system was, in turn, represented as a network of input and output flows controlled by the operator.

Figure 7.3 shows a schematic of a reboiler with all process parameters whose interrelationships were taught to the model-group in a way that subjects could make practical use of them in plant operation. Appendix 2 presents all the instructions given to this group and the process diagrams which facilitated assimilation of the material. This training method was based upon ideas of Moray et al. (1986) and Moray (1987) according to which complex industrial systems are represented as homomorphs. A homomorph is a many-to-one mapping, a partial model of the real system in the sense that it can be produced from the original by forming a reduced version of it, representing only the process parameters which are essential in controlling the system. For instance, in order to operate the reboiler of figure 7.3, the operator needs only to understand the relationships between temperature, composition and flow-rate of the input and output flows; other parameters such as viscosity, specific heat capacity etc., were not represented in this schematic as these play a minor role in plant operation. Which parts of the real system will be identified as critical in operation, can be predicted either by analytic decomposition methods (Himmelblau, 1973) or by empirical methods such as those of Conant (1976). For the purpose of this investigation, however, critical process parameters were identified with the use of the plant simulator.

A critical issue in teaching models or prototypes of systems is the extent that trainees can make effective use of these models in the performance of a task (Mann and Hammer, 1986; Rouse and Morris, 1986; Reiersen, 1985; Patrick and Haines, 1988). In order to demonstrate how the model of the plant could be used, the time-base of the simulator was adjusted to 3 seconds so that the causal-relationships between inputs and outputs are understood and used effectively; this was done only for the first two training days, in order to avoid any confounding effects from the use of the simulator in a 'predictive' mode.
Figure 7.3. A schematic of a reboiler provided to the model-group to practise plant-theory.
The subjects were also introduced to the three main sub-goals of the task description (e.g. goals 2.1, 2.2, 3), as it can be seen from figure 7.4. The shaded areas indicate that no plans were specified for achieving these goals, and they can be thought of as representing the GRS distance facing this group; however, subjects could use their plant-model to cope with this distance.

Because the model was quite extensive, this group required more time than the others in order to learn the instructions to the satisfaction of the experimenter. Since, it was necessary to record the types of 'procedures' evolved by this group during mastery of the original task as well as to examine the way in which these were carried forward to the transfer task, all control actions were logged by the simulator together with every state of the process; these 'state-action' pairs were used to identify trainees' strategies, with the additional help of collected verbal protocols.

**The practice-group**

The fourth group of subjects, which was used as a control group, was given only a short introduction to the process of distillation which was common to all groups (see appendix 2), and they were left alone to construct their own responses by experimenting with the simulator. The only form of guidance was the task description of figure 7.4; however, no further assistance was given how to organise interfacing responses into higher order goals.

This form of learning by discovery and hypothesis testing is advocated in many Computer Aided Instruction Systems which simulate certain microworlds such as steam plants, electronic equipment, and medical data bases; examples include programs such as STEAMER (Hollan et al., 1984), SOPHIE (Brown et al., 1982), GUIDON (Clancey, 1979) etc. A further reason for including this group, was to examine the sort of difficulties encountered by trainees in this sort of learning environments, where little structured advice is provided.

The procedures used by this group in the original and transfer tasks were elicited with the use of verbal protocols and 'state-action' pairs.
Figure 7.4. Task description provided to the model and practice groups.
EXPERIMENTAL HYPOTHESES

Based upon the proposed model of response learning, five hypotheses were formulated and subsequently tested in a large scale experiment. Three hypotheses concerned the transfer of common task elements, while the other two concerned nonspecific transfer effects, that is, development of planning elements and system prototypes.

Hypotheses about the acquisition and transfer of task elements

The major hypothesis of this thesis is that, forms of instruction such as models of the plant and explanations about goal-relationships will optimise transfer of task elements to new contexts. These forms of instruction will enable trainees to recognise existing responses in their repertoire as being appropriate in a new context; in the cases where these responses appear to be sub-optimal, trainees will be able to introduce the necessary modifications. In order to test this hypothesis, subjects were trained in the original task of 'carrying out the intermediate stage in distillation' and were tested in their performance of the transfer task of 'carrying out the final stage, from an established intermediate stage'. Three predictions were attempted with respect to the acquisition and transfer of task elements.

Performance at the original task and first trial of the transfer task

The 'procedures' taught to the procedures- and analysis- groups in the original task, were expected to make them perform better than the model-group, because they were developed by the author and the students in chemistry and chemical engineering after many trials on the CRISPS simulator. It is doubtful whether subjects in the model-group could come up with such effective procedures over the time schedule of the experiment, especially without the facility to use the simulator in a 'predictive' mode. However, the model of the plant would enable them to improve their performance over the transfer task to the extent that they may become better than the procedures-group which had no strong basis to generalise their procedures. Therefore, the following two hypotheses were stated:
The effect of practice on transfer

As it was felt desirable to examine whether these patterns of performance would be sustained with the increase of practice on the transfer task, the experimental groups practised another version of the transfer task on a following day. Practice would enable all groups to improve their performance on the transfer task, with the procedures-group now reaching the performance of the model-group. Therefore, the third hypothesis could be stated as follows:

3) 'All groups will improve their performance on a successive transfer task, with the procedures-group reaching the performance of the model-group; all groups will be superior to the practice-group'.

All three hypotheses about transfer of task elements will be examined in the context of three performance measures - that is, speed, control performance, and economy of operation - which are described in chapter 8. However, in order to conduct an 'in-depth' analysis of the size of transfer observed for each of the three intermediate goals and investigate the types of plans developed, all the verbal protocols and logged 'state-action' pairs will be analysed further in chapter 10.

Hypotheses about nonspecific transfer effects

When trainees appear to have mastered a complex control task, their skills and knowledge can extend beyond the mere acquisition of a set of efficient task elements e.g. intermediate goals and plans, to include forms of planning elements and system prototypes, although these may have not explicitly been taught. This is another research question addressed in the thesis. For
instance, to what extent the analysis-group will acquire system prototypes, while the model-group will acquire planning elements; or to what extent the procedures- and practice- groups will acquire these response items.

Transfer of planning elements

To investigate the issue of transfer of planning elements, the verbal protocols and 'state-action' pairs were examined from the point of view of identifying inefficient actions originated from misconceptions about goal-interactions as well as unsystematic observations of the system. As the main manifestation of the development of planning elements is the frequency at which goals 1 and 2 are successfully integrated, the following measure of Planning Elements Score (PES, in short) was compiled:

Planning Elements Score = 100 \times (1 - \frac{D}{M}) (\%);

where 'D' is the number of 'disturbances' caused to goal-2 in an effort to establish goal-1, and 'M' is the number of valve Vo manipulations in order to achieve goal-1. As a disturbance to goal-2 was perceived any change in the quality of the bottom product due to changes in the position of Vo in steps equal or greater than five units. The following hypothesis, therefore, was stated:

4) 'In both transfer tasks, the analysis- and model- groups will achieve a higher PES than the procedures-group, which will be better than the practice-group in this respect'.

Transfer of system prototypes

Transfer of system prototypes was investigated with the administration of an extensive questionnaire in the end of the experiment (see appendix 2). In order to take into account the extent to which each question was answered completely, a scale between 0 and 4 was used to assess all answers; intermediate marks 1, 2, and 3, were used when an answer was partially correct. In addition, the following Correct Answer Score (CAS, in short) was compiled:
Correct Answer Score = 100 \cdot \left( \frac{1}{n} \right) \cdot \left( \frac{1}{4} \right) \cdot \left( \sum_{i=1}^{n} Q_i \right);

where \( n \) is the number of questions addressed, and \( Q_i \) was the mark given to the \( i \)th answer. The following hypothesis, therefore, was stated:

5) 'The model- and analysis- groups will achieve a higher CAS than the procedures-group, which will be better than the practice-group in this respect'.

It is worth pointing out that the Planning Elements Score and Correct Answer Score should be perceived as a first approximation only to the measurement of nonspecific transfer effects. To understand more fully this psychological mechanism, we also need to take a closer examination of the control actions and verbal protocols; parts of chapters 9 and 10 will serve this purpose.

THE DESIGN OF THE EXPERIMENT

In order to investigate the set of transfer hypotheses, an experiment was set up which is described below. Prior to the main experiment, a preliminary study was carried out with one subject on each experimental condition; since, most of the results appeared to be in the expected direction and the conditions of training remained the same for the rest of the subjects, the results were incorporated in the main study.

Subjects

Twenty-eight postgraduates recruited from the Loughborough University pool, were randomly assigned to the four experimental groups. All subjects had 'A' and 'O' levels in physics and in chemistry, but no prior experience in the process of distillation; none of them were students in chemistry or chemical engineering. They were trained individually and were paid seven pounds at the conclusion of the training. Four of these subjects were used in the preliminary study and their results were included in the main analysis.
The transfer design

It will be recalled from chapter 2, that earlier studies in paired-associate tasks or perceptual-motor tasks, have employed various designs to control for nonspecific transfer effects. In many studies, the control group is required to perform a task equivalent to the original task on all accounts, excluding the specific similarity relation between the original and transfer tasks (see design-2 in figure 2.1). In the context of complex cognitive skills such as process control skills, it is very difficult to devise a task for the control-group which will represent all aspects of knowledge that the procedures-, analysis-, and model- groups can acquire by practising the original task, so that transfer effects cannot be attributed to these general types of knowledge but to the specific common task elements. The design-3 (figure 2.1) is also inappropriate for the study of 'internal' task transfer, because it varies the transfer task.

The design-4 has been employed by many studies in text-editing skills for testing the hypothesis that 'the learning time for a new task is determined by the number of new elements introduced'; however, this design does not seem to lend itself to the testing of the hypothesis that 'the learning time for a new task incorporating the same task elements with a previous task is determined by the learning conditions under which the common task elements were originally acquired'. On the other hand, the fore-test-post-test designs of figure 2.1, although interesting enough, require a large number of subjects which is beyond the resources of this thesis.

In the context of process control skills, practice of a set of task elements will always result in some kind of 'general knowledge' which will give rise to nonspecific transfer. However, its contribution to performance would be profound when the original task is practised to the extent that trainees have acquired such a 'general knowledge' as well as when important aspects of the transfer task are not incorporated in the representation of the original task. Both of these factors were under control in the present study, as the time schedule of the experiment does not allow subjects to proceed beyond the 'associative' stage of learning, and the transfer task incorporates the same three sub-goals of the original task; therefore, the observed transfer is not expected to have a large nonspecific component. Some degree of nonspecific transfer will take place, however, and it will be investigated in the context of the fourth and fifth experimental hypotheses.
According to the adopted transfer design, all groups have practised the same original and transfer tasks to the same extent. Performance differences between the practice-group and the other three groups will indicate the benefits of training methods other than simply interaction with the simulator. The transfer design consists of six training modules attended on six different days, within the time-interval of two weeks. The training modules were as follows:

Day-1: Short introduction to the distillation plant, followed by unaided practice to establish level-1 in column twice.

Day-2: Teaching of the main training method in order to practise the original task once; the practice-group simply practised the original task without additional instructions.

Day-3: Revision of the introduction and the training methods, followed by one practice trial on the original task; help was provided to all but the practice-group.

Day-4: Data collection from performance at two versions of the original task.

Day-5: Data collection from a version of the transfer task.

Day-6: Data collection from a second version of the transfer task, followed by a lengthy questionnaire to test general understanding of the distillation process.

To make the task more realistic, subjects were told that they were to purify a liquid mixture of 30% in acetone and 70% in water; (for a detailed introduction to the plant see appendix 2). During the second and third day, subjects were tested on the extent that they could effectively use their training methods, while assistance was offered to those who had some difficulties in doing so. Data were collected only for two trials on the original task on day-4, and two trials on the transfer task on days 5 and 6. Because subjects could remember the valve positions of previous trials, the amounts of feed and output products were changed on every new trial together with the capacity of all pumps. Thus, the optimal 'valve-position array' was different over trials. Table 7.2 displays the required feed and product specifications, while table 7.3 shows the optimal 'valve-position array' in each trial.

On transfer to the second stage of distillation, the subjects took control of the plant from an established intermediate stage, and they were required to increase the quality of the top product from 50% (weight percentage in acetone) to 68% (±1), while keeping the quality of bottom product at 21%.
TABLE 7.2: Feed and product specifications required in the experimental tasks

<table>
<thead>
<tr>
<th>DAY</th>
<th>FR1</th>
<th>Xf</th>
<th>FR11</th>
<th>Xd</th>
<th>FR3</th>
<th>Xd</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAY-2</td>
<td>1908</td>
<td>30%</td>
<td>550±50</td>
<td>50%</td>
<td>1350±50</td>
<td>21%</td>
</tr>
<tr>
<td>DAY-3</td>
<td>3128</td>
<td>30%</td>
<td>1000±50</td>
<td>50%</td>
<td>2150±50</td>
<td>21%</td>
</tr>
<tr>
<td>DAY-4A</td>
<td>2384</td>
<td>30%</td>
<td>750±50</td>
<td>50%</td>
<td>1650±50</td>
<td>21%</td>
</tr>
<tr>
<td>DAY-4B</td>
<td>3200</td>
<td>30%</td>
<td>1000±50</td>
<td>50%</td>
<td>2200±50</td>
<td>21%</td>
</tr>
<tr>
<td>DAY-5</td>
<td>1908</td>
<td>30%</td>
<td>300±50</td>
<td>68±1%</td>
<td>1550±50</td>
<td>21%</td>
</tr>
<tr>
<td>DAY-6</td>
<td>2384</td>
<td>30%</td>
<td>450±50</td>
<td>68±1%</td>
<td>1950±50</td>
<td>21%</td>
</tr>
</tbody>
</table>

TABLE 7.3: Final value positions in the experimental tasks

<table>
<thead>
<tr>
<th>DAY</th>
<th>Ua</th>
<th>Ub</th>
<th>Uc</th>
<th>Ud</th>
<th>Ur</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAY-2</td>
<td>48</td>
<td>50</td>
<td>50</td>
<td>62</td>
<td>00</td>
</tr>
<tr>
<td>DAY-3</td>
<td>70</td>
<td>80</td>
<td>80</td>
<td>68</td>
<td>00</td>
</tr>
<tr>
<td>DAY-4A</td>
<td>20</td>
<td>68</td>
<td>68</td>
<td>59</td>
<td>00</td>
</tr>
<tr>
<td>DAY-4B</td>
<td>25</td>
<td>82</td>
<td>82</td>
<td>62</td>
<td>00</td>
</tr>
<tr>
<td>DAY-5</td>
<td>40</td>
<td>70</td>
<td>70</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>DAY-6</td>
<td>20</td>
<td>88</td>
<td>88</td>
<td>35</td>
<td>60</td>
</tr>
</tbody>
</table>
In addition, the tolerance of the level-1 which was (±2) in the original task was reduced to (0) in the transfer task. On the contrary, the pressure profile was allowed to increase up to 2 at., instead of 1.5 at. in the original task.

Because a considerable amount of time could be spent in adjusting the rate of feedflow, subjects were told the target position of valve \( V_i \) which corresponded to the specified amount of feed. Thus, they started both the first and final stage in distillation from an established feedflow. Finally, they were told that they must perform the tasks as quickly as possible, without consuming a lot of energy or disturbing established product qualities.

Because it was difficult to judge how close the current state of the process was to the equilibrium stable state, subjects would terminate the trial when the product qualities were on target for seven successive production runs, while the two levels would be on target for at least three production runs. All subjects spent one and a half hours on each day, apart from day-5 in which they spend half an hour approximately; thus, the whole training course required eight hours approximately.

In order to record the goals set by trainees during the performance of the original and transfer tasks, the experimenter asked them a number of questions relating to their strategy. To minimise any interference with the primary task, a minimum number of questions were asked in these cases where their goals were not clear to the experimenter. The verbal protocols collected with this method were a valuable tool in the 'in-depth' analysis of transfer conducted in chapters 9 and 10.

**CONCLUSION**

Process control tasks are very complex tasks, and although they may have many subordinate task elements in common, the amount of transfer will be determined by the extent to which trainees recognise these particular similarity relationships. Therefore, transfer will be affected by factors such as conditions under which task elements were originally encoded, and ease with which these elements can be retrieved and adapted to new situations. In addition, because of the flexibility of process control tasks, a particular element may be performed in many different ways, in which case the trainee is set a
difficult decision task to select the most efficient ones. This may imply that learning methods may have to play an important role in the transfer of skills even when two tasks seem to be formally similar e.g. similar types of plans and intermediate goals.

Based upon the proposed model of response learning, three hypotheses were formulated regarding the effect of instruction upon transfer of task elements, which constitutes the major focus of the thesis. The following chapter 8, presents the experimental results in terms of a number of performance measures. The other two hypotheses about nonspecific transfer will be examined in chapter 10.
CHAPTER 8

AN EXAMINATION OF THE TRANSFER OF TASK ELEMENTS THROUGH THE ANALYSIS OF PERFORMANCE MEASURES

SUMMARY

This chapter presents the results of a comparison between four experimental groups in the performance of two original and two transfer tasks in terms of speed, control performance, and economy of operation. The three hypotheses concerning transfer of task elements were supported by the results mainly for the measures of speed and control performance. However, no significant differences were found in the economy aspect of the operator's strategy, particularly for the transfer task; various plausible explanations are cited in the end of this chapter.

As a generalisation, training methods which facilitated acquisition of skills did not necessarily support transfer to new contexts of application. However, the analysis-group achieved a good performance in both the original and transfer tasks; the training information provided to this group may, therefore, indicate the type of knowledge and skills required to integrate criteria of acquisition and transfer of skills. Finally, some degree of within-group variability occurred, with a tendency for the more competent trainees of the less efficient method to approach the performance of the less competent trainees of the more efficient method; this issue, is elaborated further in this chapter.

INTRODUCTION

The four experimental groups, that is, the procedures-, the analysis-, the model- and the practice-groups were trained in the original task of 'carrying out the intermediate stage in distillation' and they were tested in the performance of the transfer task of 'carrying out the final stage in distillation, from an established intermediate stage'. The performance of the groups on the original task was also measured, during the practice of two versions of the original task.
in the fourth day of the training. Separate from the issue of the \textit{first-shot transfer} in the fifth day of training, it was an examination of the \textit{effects of practice} upon the performance of the transfer task, as it was tested on another version of the same task in the sixth day of training.

Group differences in the performance of the transfer task are supposed to have been mainly due to the transfer of task elements developed in the context of the original task, and to a lesser extent due to a nonspecific transfer mechanism. There are two main reasons which can justify such an assumption: (i) the two tasks consist broadly of three common goals, and (ii) within the time schedule allowed, subjects are not expected to proceed beyond the 'associative' stage of learning and acquire a well-established kind of 'general knowledge' which may give rise to nonspecific transfer effects. Therefore, any performance differences reported in this chapter are supposed to indicate the degree of transfer of 'common' task elements.

\textbf{RESULTS}

This section describes the performance measures used to compare the performance of the four groups in the original and transfer tasks, and presents the experimental results with reference to the three hypotheses about the acquisition and transfer of task elements. From all the performance measures, only those showing non-significant correlations with each other were selected, since they were perceived as corresponding to different aspects of operator's strategy.

Performance measures

Three different measures of performance were taken, namely, speed, control performance and economy of operation which are described below.

\textit{Speed} was measured as the \textit{time} required to bring the plant into the specified conditions as well as the number of \textit{production runs} required to complete the task.
Control performance was measured as the absolute deviation of each product quality from its target value, and the overall control performance was the sum of the two deviations for the bottom and top product qualities. The following formula shows the overall control performance:

$$\text{Overall control performance} = \sum_{i=1}^{n} ( (X_{b}(i)-X_{b,\text{target}}) + (X_{d}(i)-X_{d,\text{target}}) ) ;$$

where $X_{b}(i)$ and $X_{d}(i)$ are the bottom and top product qualities at run $(i)$, and $n$ is the total number of runs used in a trial.

As a measure of economy of operation was taken the amount of energy consumed in the reboiler, in the condenser, and the total amount of energy consumed. Because energy consumption was also determined by the amount of feed getting into the system, the results were divided by the target values of $V_b$ or $V_c$ as these were shown in table 7.3 (see chapter 7). In addition, the results were normalised with respect to the number of production runs used. The following formula shows the normalised total energy consumption:

$$\text{Normalised total energy consumption} = (0.02/n) \cdot \sum_{i=1}^{n} ( P_{b}^{\ast}(V_{b}(i)/V_{b,\text{target}}) + P_{c}^{\ast}(V_{c}(i)/V_{c,\text{target}}) ) ;$$

where $V_{b}(i)$ and $V_{c}(i)$ are valve positions at run $(i)$.

The term $(1/n)$ in the above equation indicates that the energy consumption has been normalised to the total amount of runs, while the term $(0.02)$ is a coefficient of unit transformation.

Statistical tests applied

All performance scores were analysed with the method of two-way repeated measures analysis of variance. A 2 (trial) X 4 (training method) analysis of variance was applied to the data of trials 1 and 2 of the original task (on day 4) as well as to the data of trials 3 and 4 of the transfer task (on days 5 and 6). Appendix I shows all the ANOVA summary tables.

Where significant method-effects were yielded on either trials, these were analysed with a two-tailed $t$-test, also known as the protected $t$-test, or Fisher's least significant difference test. The $MS$ error from the analysis of variance
was used as an estimate of the standard error of the differences in the two-tailed t-test. On the other hand, significant differences of trial-effects were indicated by the calculated F-ratio only, since there were only two trials for each stage in distillation. All statistical formulas were taken from a statistical textbook published by Winer (1971).

There is a controversy over the use of statistical tests for individual comparisons, with some authors favouring *post-hoc* comparisons (i.e. Tukey test) and others favouring *ad-hoc* comparisons which have a greater chance of yielding significant differences (i.e. two-tailed t-test). In this thesis only *ad-hoc* comparisons were made, because performance differences had carefully been planned through the design of a set of different training methods.

Before the analysis of the main results, all performance measures were correlated to the number of 'production runs' used over a single trial, in order to examine the degree to which different aspects of operator strategy were related to each other.

Correlations between performance measures

Table 8.1 summarises the correlations of all measures of performance to the number of 'production runs' used in each trial. Total energy consumption before the normalisation to the number of production runs used, is also presented in the third column of table 8.1.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time (mins)</th>
<th>Overall control performance</th>
<th>Total energy consumption</th>
<th>Normalised total energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.89*</td>
<td>0.75*</td>
<td>0.89*</td>
<td>0.54*</td>
</tr>
<tr>
<td>2</td>
<td>0.92*</td>
<td>0.68*</td>
<td>0.79*</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>0.91*</td>
<td>0.82*</td>
<td>0.97*</td>
<td>0.11</td>
</tr>
<tr>
<td>4</td>
<td>0.96*</td>
<td>0.74*</td>
<td>0.98*</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Key: (*) Significance of correlations is $p < 0.01$

---
From table 8.1, it can be seen that the amount of time to perform the task (in minutes) is very highly correlated to the number of 'runs' used, which can provide justification for using the number of 'runs' as an alternative measure of speed of performance.

Total energy consumption is also highly correlated to the number of 'runs', which was expected since the amounts of heating and cooling agents used are proportional to the time taken to complete the task. However, when total energy consumption was normalised to the number of 'runs' used, the correlation was significantly reduced. Therefore, normalised energy consumption appears to be a better measure for examining the economy aspect of operator's strategy, although it does not correspond to the actual 'energy cost' of running the plant. When the concern is over such a cost rather than operator's strategy, the former measure should be chosen.

From the same table 8.1, it can be seen that the overall control performance is moderately to highly correlated to the number of 'runs' used. In general, this result was not expected because the qualities of the products do not seem to vary with the amount of time to complete the task, in any 'direct' manner. It is conceivable that subjects can engage in a number of activities which do not affect product qualities such as 'adjusting the level-1 in the column before starting evaporation', or 'adjusting level-3 in the drum when product qualities have already been established'.

In general, there are two factors which affect the degree of correlation: (i) the overall variance of the number of 'runs' used, which is greater than the same variance for each individual group, and hence the high correlation observed, and (ii) the use of heterogeneous samples (in this case, different training groups) which should actually result in lower correlation (Howell, 1982). In order to further investigate this issue, the correlation of the overall control performance was taken for each individual group, rather than all groups on the same trial; the results indicated that the correlations were much more lower, in most cases. As an example, the correlation of the overall control performance on trial-3 \( (r=0.82) \) is broken down into correlations for each group (see bottom part of figure 8.1), and it is compared to the correlation of the total energy consumption on trial-2 (which has a similar correlation \( r=0.79 \)). From figure 8.1 it can be seen that, for each group, the total energy consumption is much better correlated to the number of 'runs' than the overall control performance does, although the overall correlations are similar \( (r=0.79 \text{ versus } r=0.82) \).
Figure 8.1. Correlations of energy consumption and control performance to the number of production runs.
Therefore, the control aspect of operator's strategy can adequately be expressed by this measure, without any requirement to normalise it to the number of 'runs' used.

**Speed of performance**

Figures 8.2 and 8.3 show the speed of performance of the four groups in terms of the number of 'runs' and 'time' (in minutes) to complete the original (trials 1 and 2) and transfer (trials 3 and 4) tasks.

A two-way repeated measures ANOVA for the original task, showed significant differences between methods, for both the number of 'runs' ($F=11.66; df=3,24; p<0.001$) and the 'time' to complete the trials ($F=9.55; df=3,24; p<0.001$). The interaction was not significant for both the number of 'runs' ($F=0.35; df=3,24; p=N.S.$) and the 'time', ($F=0.03; df=3,24; p=N.S.$). A two-tailed t-test upon the main methods-effects in terms of 'runs', showed that the procedures-group performed significantly better than both the practice-group ($t=5.505; df=24; p<0.001$) and the model-group ($t=2.795; df=24; p<0.025$); the analysis-group performed significantly better than the practice-group ($t=4.502; df=24; p<0.001$) but not than the model-group ($t=1.792; df=24; p=N.S.$); finally, the model-group performed significantly better than the practice-group ($t=2.710; df=24; p<0.025$). A similar pattern of differences appeared for the measure of 'time' to complete the task, apart from the fact that the difference between the model- and practice- groups was not significant ($t=1.27; df=24; p=N.S.$). All groups appeared to perform faster on the second trial of the original task, for both the number of 'runs' ($F=9.3; df=1,24; p<0.01$) and 'time' to complete the task ($F=10.12; df=1,24; p<0.01$).

The above pattern of performance has changed on transfer to the final stage in distillation, where the analysis of variance showed significant differences between methods for both the number of 'runs' ($F=13.93; df=3,24; p<0.001$) and 'time' ($F=14.97; df=3,24; p<0.001$). The interaction appeared to be significant only for the number of 'runs' ($F=4.12; df=3,24; p<0.025$), while it failed to reach significance for the 'time' ($F=2.78; df=3,24; p=N.S.$). With respect to the measure of production runs, significant simple method-effects were found in both trial-3 ($F=17.27; df=3,24; p<0.001$) and trial-4 ($F=4.41; df=3,24; p<0.025$).
Figure 8.2. Number of production-runs used.
Figure 8.3. Time taken to complete a trial.
Since group differences appeared to follow similar patterns for the two measures of speed of performance, individual comparisons were made only for the number of 'runs'. A two-tailed t-test on the simple method-effects of the first attempt on the transfer task (trial-3) showed that all groups performed significantly better than the practice-group; the highest significance was for the analysis-group ($t=6.749; \text{df}=24; p<0.001$), then for the model-group ($t=5.25; \text{df}=24; p<0.001$), and finally for the procedures-group ($t=2.972; \text{df}=24; p<0.01$). On the same trial, the procedures-group performed significantly worse than both the analysis-group ($t=3.777; \text{df}=24; p<0.001$) and the model-group ($t=2.278; \text{df}=24; p<0.05$).

These group differences were no longer prevalent on a successive practice with the transfer task (trial-4), for both the measures of 'runs' ($F=33.67; \text{df}=1,24; p<0.001$) and 'time' ($F=30.05; \text{df}=1,24; p<0.001$). For the measure of 'runs', the differences were due to the procedures-group ($F=9.02; \text{df}=1,24; p<0.01$) and the practice-group ($F=32.85; \text{df}=1,24; p<0.001$), which achieved higher rates of learning than the other groups. As a result, only the analysis-group performed significantly better than the procedures-group ($t=3.65; \text{df}=24; p<0.025$) and practice-group ($t=3.457; \text{df}=24; p<0.01$), on trial-4. Similar patterns of performance appeared for the 'time' to complete the task, however, the analysis-group performed significantly better than the model-group as well ($t=2.396; \text{df}=24; p<0.05$). Overall then, the analysis-group performed better than all other groups on trial-4.

Control performance

Figure 8.4 displays the observed differences in the overall control performance, as this is measured in terms of the 'absolute deviation of both product qualities from the target values'. A two-way repeated measures ANOVA for the original task showed significant method-effects ($F=7.48; \text{df}=3,24; \ p<0.002$) and no significant interaction ($F=1.71; \text{df}=3,24; \ p=N.S.$). A two-tailed t-test upon the main method-effects showed that the procedures-group performed significantly better than both the practice-group ($t=3.65; \text{df}=24; p<0.01$) and the model-group ($t=3.01; \text{df}=24; p<0.01$); the analysis-group performed significantly better than the practice-group ($t=3.80; \text{df}=24; p<0.001$) and this time, also better than the model-group ($t=3.16; \text{df}=24; p>0.01$); finally, the model-group did not perform significantly better than the practice-group ($t=0.64; \text{df}=24; p=N.S.$).
Figure 8.4. Overall control performance.
However, groups did not seem to improve their control performance on the second trial of the original task (F=1.26; df=1,24; p=N.S.), one reason being that the model-group appeared to have degraded its performance on trial-2.

Again, the patterns of performance have changed on transfer to the final stage of distillation, where the analysis of variance showed significant differences between methods (F=5.74; df=3,24; p<0.01) as well as a significant interaction (F=8.03; df=3,24; p<0.001). If we look at the simple method-effects, significant differences were found in trial-3 (F=9.64; df=3,24; p<0.001) but not in trial-4 (F=2.38; df=3,24; p=N.S.). A two-tailed t-test upon the simple method-effects on the first attempt on the transfer task (trial-3), showed that all groups performed significantly better than the practice-group; the highest significance was for the analysis-group (t=5.025; df=24; p<0.001), then for the model-group (t=4.04; df=24; p<0.001) and finally, for the procedures-group (t=2.412; df=24; p<0.05). On the same trial, the procedures-group performed significantly worse than the analysis-group (t=2.61; df=24; p<0.025) but this time, not significantly worse than the model-group (t=1.627; df=24; p=N.S.).

These group differences were no longer prevalent on successive practice with the transfer task (F=80.86; df=1,24; p<0.001), because all but the model group improved their performance significantly on trial-4; the rates of learning were higher for the practice-group (F=64.59; df=1,24; p<0.001), then for the procedures-group (F=28.56 df=1,24; p<0.001) and finally, for the analysis-group (F=9.50; df=1,24; p<0.01). As a result, only the analysis-group performed significantly better than the practice-group (t=2.623; df=24; p<0.025), on trial-4.

An interesting result was that while all groups appeared to improve their performance on trial-2, the model-group degraded its performance. On the other hand, as it can be seen from figure 8.4, all groups degraded their performances on transfer to the final stage of distillation (trial-3), apart from the model-group which improved its performance.

Further investigation of the control performance indicated that, while the 'absolute deviation from the target quality of the top product' followed a similar pattern of performance, the 'absolute deviation from the target quality of the bottom quality' had a different pattern of rates of learning. From figure 8.5 it can be seen that, the model-group did not degrade its performance on trial-2 and that all groups but the procedures-group improved their performance upon transfer to trial-3.
Figure 8.5. Control performance of the bottom product.
However, group differences were maintained on each particular trial, regardless of the different rates of learning. Therefore, the procedures- and analysis-groups appeared to perform better than the model- and practice- groups on the original task, while the model-group improved its performance considerably on the transfer task and performed better than the procedures-group on trial-3.

### Economy of operation

Figure 8.6 shows the observed differences in terms of the total energy consumption normalised to the number of 'runs' used. A two-way repeated measures ANOVA for the original task showed significant method-effects (\(F=6.99; \text{df}=3,24; \ p<0.01\)) and no significant interaction (\(F=1.65; \text{df}=3,24; \ p=\text{N.S.}\)). A two-tailed t-test upon the main method-effects showed that the procedures-group performed significantly better than both the practice-group (\(t=3.09; \text{df}=24; \ p<0.01\)) and the model-group (\(t=4.35; \text{df}=24; \ p<0.001\)); the analysis-group did not perform significantly better than the practice-group (\(t=1.4; \text{df}=24; \ p=\text{N.S.}\)) but it was significantly better than the model-group (\(t=2.66; \text{df}=24; \ p<0.05\)); finally, the model- and practice- groups did not differ significantly in their performance (\(t=1.256; \text{df}=24; \ p=\text{N.S.}\)). Again, groups did not seem to improve their control performance on the second trial of the original task (\(F=1.15; \text{df}=1,24; \ p=\text{N.S.}\)).

A surprising result was that upon transfer to the final stage in distillation (trials 3 and 4), no significant group differences were found (\(F=0.75; \text{df}=3,24; \ p=\text{N.S.}\)) and no interaction (\(F=1.53; \text{df}=3,24; \ p=\text{N.S.}\)). However, the rates of learning on the second version of the transfer task (trial-4) were significantly higher (\(F=21.92; \text{df}=1,24; \ p<0.001\)); the significance seems to be due to the model- and practice- groups mainly.

Further investigation of the amounts of heating and cooling agents used, showed that these followed identical patterns with the overall energy consumption. Therefore, there were no significant differences in the economy aspect of the subjects' strategies. It is worth noting that this does not necessarily mean that all groups consumed the same amount of energy on the transfer task. It has been shown in table 8.1, that when energy consumption is not normalised it is highly correlated to the number of 'runs'; thus, a similar pattern of performance differences is likely to emerge for the non-normalised total energy consumption, as it was the case for the number of 'runs'.

Figure 8.6. Normalised total energy consumption.
In this section, the results of this experiment will be discussed in the context of the three hypotheses concerning performance on the original task and transfer of task elements to the two versions of the transfer task. As it was felt necessary that different performance measures would reveal different aspects of operator's strategy, an attempt was made to examine the degree of correlation between these measures. Since total energy consumption was found to be highly correlated to speed, only the normalised measure was used as an indication of the economy aspect of operation. On the other hand, the overall control performance was moderately to highly correlated to speed, however, this proved to be the result of pooling the group variances within the same trial; the correlation of performance to speed of each individual group was found to be moderate to low. Therefore, the selected measures of performance - that is, number of production runs, overall control performance, and normalised total energy consumption - reflected different aspects of behaviour.

Performance at the original task

The first experimental hypothesis concerned the performance at the original task and stated that 'all groups will perform better than the practice-group, with the analysis- and procedures- groups being superior to the model-group'. In addition it was assumed that the performance of all groups will tend to stabilise during the two versions of the original task on day-4. Indeed, most measures of performance indicated that no significant improvements occurred in trial-2, with the exception of the practice-group which appeared to learn faster on the basis of practising with the simulator.

The generalisation that all groups would perform significantly better than the practice-group seems to be valid for the measures of speed and control performance; the only exception was the control performance of the model-group which was not significantly different than the one of the practice-group. On the other hand, it was only the procedures-group which had a significantly better economical strategy than the practice-group; the fact that the difference in energy consumption between the analysis- and practice- groups was not significant is justifiable in the sense that the analysis-group was not provided with any explicit instructions 'how to sequence the production and
condensation of vapours', and thus, they had to construct a response for time-sharing these operations (see plan-2.2.1 in chapter 7).

It was interesting, however, that the model-group was not significantly different from the practice-group in terms of both control performance and energy consumption. From figure 8.4 it can be seen that, the model-group is still experimenting with different ideas as its control performance on trial-2 is poorer than the one on trial-1; however, subjects were in a better position to control the quality of the bottom product (see figure 8.5), while they have not eventually succeeded in mastering how to tackle the problem with the contamination of the quality of the top product in the drum. On the other hand, they were not significantly different from the practice-group in the economy aspect of operation, one reason being that they may have sacrificed economy to improve the way the quality of the top product should be controlled.

The other part of the hypothesis that the procedures- and analysis- groups will be superior to the model-group has also been supported. It was only the difference in the speed of performance between the analysis- and model- groups which was not significant. Again, it is premature to speculate on this difference, before a thorough examination of each individual subject's record is made. It is quite difficult to understand the precise reasons behind these differences, before an introspection is made into their protocols and 'state-action' pairs.

**Performance at the transfer task**

Performance at the two transfer tasks was assumed to follow different patterns, and for this reason, another two hypotheses were formulated. The first one concerned performance on the first transfer task (trial-3) and stated that 'all groups will perform better than the practice-group, with the analysis-group being superior to all other groups, and the model group performing better than the procedures-group'. The other hypothesis concerned practice-effects on a successive transfer task (trial-4) and stated that 'all groups will improve their performance, with the procedures-group reaching the performance of the model-group; all groups will maintain their superiority to the practice-group'.
Indeed, the significant interactions and significant trial effects (trials 3 and 4) indicated that performance on the transfer tasks followed different patterns, which could be described in terms of simple method-effects on each trial, rather than mean method-effects which was the case in the performance of the original tasks.

The first hypothesis that 'all groups will be superior to the practice-group, on trial-3' has been supported for all measures but the energy consumption. In fact, there were no significant simple method-effects for this measure either on trial 3 or 4. An important reason for this, might be that most subjects mastered the skill of 'how to fully condense the produced vapours' on transfer to the second stage of distillation, as they came up with a 'rule of thumb' that the flows of the heating and cooling agents should be adjusted at similar rates. An 'in-depth' examination of the subjects' records of control actions showed that this measure may have been confounded by the nature of the transfer task. Specifically, subjects had to move from a low to a high energy mode when performing the original and transfer tasks. However, because this transition period was quite shorter for the transfer task, subjects had to stay on the high energy mode most of their time and as a result, any individual differences in regulating the energy mode were obscured; hence the non-significant differences in this measure of performance during the performance of the transfer tasks.

The hypothesis that 'the analysis-group will be superior to all other groups' was partially supported. In fact the analysis-group was significantly better than the procedures- and practice- groups, but not significantly better than the model group. Only in trial-4, this difference reached significance for the measure of 'time' to complete the task. Table 8.2 shows a comparison between the analysis- and model- groups in terms of speed and control performances, on the basis of their percentage difference with respect to their mean score.

From this table, it can be seen that there is a difference between the two groups of the size of 17.44 % to 20.32 % for their speed, and of 18.11 % for their control performance; although, the difference of their means is considerable, it was not statistically significant. An important reason for this might be the large individual differences within the model-group.
Table 8.2.  
A comparison between the analysis and model groups.

<table>
<thead>
<tr>
<th></th>
<th>'Runs'-3</th>
<th>'Time'-3</th>
<th>'Cntrl'-3</th>
<th>'Runs'-4</th>
<th>'Time'-4</th>
<th>'Cntrl'-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>analysis-group</td>
<td>87.57</td>
<td>24.71</td>
<td>356.45</td>
<td>73.57</td>
<td>21.00 *</td>
<td>248.79</td>
</tr>
<tr>
<td>model-group</td>
<td>104.30</td>
<td>30.30</td>
<td>427.44</td>
<td>92.86</td>
<td>27.39 *</td>
<td>374.28</td>
</tr>
<tr>
<td>mean score</td>
<td>95.94</td>
<td>27.51</td>
<td>391.92</td>
<td>83.21</td>
<td>24.20</td>
<td>311.54</td>
</tr>
<tr>
<td>difference</td>
<td>17.44 %</td>
<td>20.32 %</td>
<td>18.11 %</td>
<td>23.32 %</td>
<td>26.41 %</td>
<td>40.28 %</td>
</tr>
</tbody>
</table>

Key: (*) significance of differences is p < 0.05;  
'Cntrl': control performance.
From figures 8.2, 8.3 and 8.4, it can be seen that for these measures the standard deviations for the model group were 23.04 'runs', 7.36 mins, and 84.11 units of control performance in comparison to 14.88, 5.19 and 50.05 of the analysis group. In general then, it seems that the analysis-group was better than the model-group, however, the performance of some subjects within these two groups must be at the same level. The role of individual differences within groups will be addressed in the next section.

For similar reasons, on trial-3, the model-group performed significantly better than the procedures-group only in terms of speed of performance, while a difference of the size of 24% was apparent for their control performance, which was not significant.

This pattern of group-differences has changed in the second day of practice with the transfer task (trial-4). The hypothesis that 'all groups will improve their performance' was supported mainly for the procedures- and practice-groups for all measures of performance. The analysis-group improved significantly in terms of control performance only, while the model-group in terms of energy consumption. In addition, the procedures-group appeared to be equivalent to the model-group in all aspects of performance, since their differences were small and failed to reach significance.

The hypothesis that 'all groups will be superior to the practice group' was partially supported only. It was the analysis-group only which performed significantly better than the practice-group in terms of speed and control performance. Again, large individual differences within the practice-group could be a plausible explanation. The fact that, no instructions were given to the practice-group in order to ensure conformity of performance may explain the large individual differences observed for this group.

In summary then, as it can be seen from table 8.3, most of the hypotheses put forward were supported. However, the fact that people at different groups performed at similar levels deserves further attention itself.
### Table 8.3. Summary of experimental findings.

<table>
<thead>
<tr>
<th>Measures of performance</th>
<th>Original tasks (trials 1 and 2)</th>
<th>Transfer task (trial-3)</th>
<th>Transfer task (trial-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed, (number of runs)</td>
<td>(p, o) &gt; m &gt; c; (a - m) difference is N.S</td>
<td>(a, m) &gt; p &gt; c; (a - m) difference is 17.5% but N.S</td>
<td>a &gt; (p, c); m is in between the other groups</td>
</tr>
<tr>
<td>Overall control performance</td>
<td>(p, o) &gt; m = c</td>
<td>(a, m) &gt; p &gt; c; (a - m) difference is 18% but N.S (m - p) difference is 24% but N.S</td>
<td>a &gt; c; (m, p) are in between the other groups</td>
</tr>
<tr>
<td>Normalised total energy consumption</td>
<td>(p, o) &gt; m &lt; c; (a - c) and (m - c) differences are N.S</td>
<td>No differences</td>
<td>No differences</td>
</tr>
</tbody>
</table>

**KEY:** N.S: non-significant; >: superior to; <: inferior to; =: equivalent to; p: procedures-group; o: analysis-group; m: model-group; c: practice or control group.
THE ROLE OF INDIVIDUAL DIFFERENCES

Large individual differences in control and diagnostic performance have troubled researchers and trainers alike. In most experimental designs, between-subjects variation is dealt with by random allocation of subjects to experimental and control groups. Unfortunately even after randomization, many subtle but nevertheless important experimental effects could be overlooked if the within-groups variance is large. Although large individual differences have often been reported (e.g. West and Clark, 1974; Duncan, 1971; Rouse and Hunt, 1984), an analysis of what constitutes these differences has been missing from the published literature.

One method for controlling large individual differences is to pre-test subjects on tasks similar to those under investigation, prior to any experimental manipulations (Duncan, 1971; Brooke et al., 1981). Level of ability can then be manipulated as an additional independent variable in later statistical analyses. To some extent, the use of pre-testing measures are unsatisfactory because they do not give any indication concerning possible psychological differences between subjects. Another approach which seems to be more justifiable in this respect, is to refine the measures by which levels of control strategy are assessed. Thus, instead of using global indices of efficiency, fine-grained measures may reveal important individual differences in operators' strategies. For instance, Bainbridge (1974) has used measures such as 'number of parameters being considered', 'accuracy of assessments of the effects of control actions', and closed- versus open-loop strategies. In this investigation, individual differences will be considered in terms of the types of plans adopted by subjects as well as development of planning elements and system prototypes (see chapters 9 and 10 for a detailed discussion). However, a first consideration is made in this section in terms of the individual scores achieved for each performance measure which are displayed in figures 8.7 and 8.8.

The groups were ranked in different orders in the two tasks which correspond to the observed performance differences. That is, the four groups were put in the following order for the original task: procedures-, analysis-, model-, and practice- groups; while, for the transfer tasks, the order was changed to: analysis-, model-, procedures-, and practice- groups.
Figure 8.7. Individual differences observed in the performance of the original task.
Figure 8.8. Individual differences observed in the performance of the transfer task.
With respect to the measures of speed and control performance, figure 8.7 may indicate that variability within the most efficient procedures- and analysis- groups is smaller than variability within the model- and practice- groups. On the other hand, it may be seen from figure 8.8 that, as the model-group improves its performance relatively to the procedures- and practice- groups so its variability reduces; while the practice-group which achieved the lowest scores maintains its large variability. It may appear then that 'the more effective a training method is proved to be, the smaller the within-groups variability becomes'.

In fact, this is an interesting speculation which has been made quite often in the training literature. The purpose of any training method would be to constrain learner's behaviour in a way that performance conforms to a specified standard of expertise; it may seem reasonable then, that the less effective training methods will not achieve this aim since individuals would behave in many different ways and this may result in large within-groups variability. To test this speculation, the means of performance of each group were correlated to their standard deviations. To this extent, a non-parametric test was chosen since the assumption that the results would come from a normal distribution could not be made (see table 8.4 for the Spearman correlation coefficients).

**Table 8.4.**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Number of runs</th>
<th>Overall control performance</th>
<th>Normalised total energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.60</td>
<td>0.80</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>1.00*</td>
<td>1.00*</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.80</td>
<td>1.00*</td>
<td>1.00*</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>0.40</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Key: (*) Significance of correlations is \( p < 0.05 \)

The results show that most correlations have failed to reach significance, although some of them were of a high value. One reason which may account for any differences to find significant correlations between means and standard deviations in 'learning'-experiments may concern the small size of the training methods tested (\( N=4 \), for this study). However, some of these correlations
might have reached significance, had the average values of the means and standard deviations of the two more effective methods been compared to the ones of the less effective methods.

Tied to this question of within-groups variability is the issue of individual learning styles, with some learners favouring one type of training rather than another which may appear to be even more effective in general terms. For instance, some individuals of the model-group were as fast as others of the procedures-group in the performance of the original task (see figure 8.7), although the latter training method proved to be more effective in the acquisition of skill. These learners explained that they were quite happy with exploring the behaviour of the plant based upon the model they were provided with, and this may account for the fact that a more 'active' way of learning - than merely following procedures- may be more appropriate for those individuals. This issue of catering for individual differences in the design of instruction deserves further examination and it is discussed in chapter 10 in greater detail.

CONCLUSION

The results reported in this chapter provide support for the three hypotheses put forward with respect to the performance of the four groups on the original and transfer tasks. However, differences in the economy aspect of operation were not significant mainly due to the development of 'rules-of-thumb' and the nature of the transfer task which required subjects to stay on the high energy mode for prolonged periods.

The finding that all groups performed better than the practice-group may support the assumption made in the proposed HTA that 'task elements similar in form may prompt an individual to adopt similar psychological processes and transfer will occur'. However, when mastery of a task is not supported by any form of extrinsic training information such as a model of the plant, goal interrelationships etc., transfer may not reach significant levels; this can be concluded by the inferior performance of the procedures-group to the model- and analysis- groups on the transfer tasks.
Another conclusion which may be attempted from the performance of the model- and procedures- groups is that training methods which facilitate acquisition of skill may not necessarily support transfer to new situations. The training information provided to the analysis-group may indicate the type of knowledge required to integrate both criteria of acquisition and transfer of skills.

Finally, the variability in the performance of each group points out the importance of individual learning styles in the design of instruction. In order to carry out an 'in-depth' analysis of the transfer of each intermediate goal and investigate the types of plans adopted by different trainees, the verbal protocols and 'state-action' pairs which collected during the experiment are analysed and discussed further in the following two chapters.
CHAPTER 9

ANALYSIS AND INTERPRETATION OF INDIVIDUAL RECORDS OF ACHIEVEMENT

SUMMARY

The purpose of this chapter is to demonstrate a method of an 'in-depth' analysis of trainees' behaviour based upon recorded 'state-action' pairs, verbal protocols, and post-experimental interviews and questionnaires. All this information which constitutes the records of achievement of trainees was necessary in order to investigate the transfer of sub-goals, efficiency of plans, and types of errors and misconceptions observed in a more detailed manner. Although the final results will be presented in the next chapter, the way in which this information was generated will be illustrated here. Specifically, this chapter has the following aims:

- To demonstrate the kind of difficulties involved in plan recognition and thus, elicitation of fine-grained measures of performance which will be used to assess the effect of instruction upon both specific and non-specific transfer.

- To highlight two important aspects of process control tasks, namely, multi-tasking and performance flexibility.

- To identify factors which are likely to affect the amount of transfer of task elements observed in this study such as mapping relationships between system prototypes and plans, development of 'rules of thumb', and complexity of the system.

- To gain an insight into the adequacy of formalisation of the existing plan taxonomy, which will be evaluated in the next chapter more thoroughly.

To illustrate the adopted approach, a small number of individual records of achievement - representative of the observed group differences - will be
presented in this chapter. The methods employed by the subjects to achieve various goals have been ranked in terms of their 'efficiency' in comparison to a set of alternative methods used by other trainees as well as by the 'experts' who participated in the pilot study.

INTRODUCTION

So far, the different patterns of group performances at the original and transfer tasks, and the different rates of learning on successive trials were examined using global indices of efficiency such as speed, control performance, and economy of operation. Although group differences along these indices can make clear implications for the optimisation of plant production - and thus, they are highly valued by plant management - they reveal little about the actual behaviour of trainees and cannot account for the individual differences observed. In addition, they do not provide a firm basis to assess the extent that different types of instruction affect transfer of goals and plan construction or adaptation, which constitutes the focus of this investigation.

In order to enable such an 'in-depth' examination of trainees' behaviour, a number of fine-grained measures were derived from the analysis of control actions, verbal protocols, interviews, and questionnaires; these measures include: 'efficiency' of type of plan adopted, amount of 'disturbance' caused to previously established goals, number of errors and misconceptions observed and so forth. Eliciting these aspects of performance from a description of observed actions, raises the issue of plan recognition which has attracted so much attention in the development of Intelligent Tutoring Systems (Sleeman and Brown, 1982). Ascribing goals and plans to trainees' actions is not an effortless process, particularly in process control environments where problems are ill-defined and a whole repertoire of skills is required.

THE PLAN RECOGNITION PROBLEM

It has been argued, in previous chapters, that understanding the sub-goals and plans that trainees employ in order to perform a task would enable us to assess the effects of different training methods upon the size of transfer of task
elements as well as the development of planning elements and conceptual knowledge of the system. The major source of information about trainees actions were the pairs of 'system state - control action' recorded by the plant simulator. However, recognising trainees plans on the basis of this information encounters a number of problems which have to do with the nature of process control tasks as complex and flexible cognitive tasks. Specifically, such a 'data-driven' approach cannot account for the following aspects of performance:

- **Complex performance or multi-tasking**, where trainees can set themselves more than one goals to achieve either because these can be carried out concurrently as well-practised responses, or because time-sharing may be the best way to cope with potential goal interactions. Although it is possible to recognise that more than one goals have been pursued, it is still difficult to identify each of them solely on the basis of the information provided in the control actions.

- **Flexible performance**, where the same goal can be achieved by several plans, yet some of them might be unknown to the interpreter.

- **Mistaken performance**, where an incorrect plan or 'erroneous rule' has been developed. This is usually the case in the initial stages of learning and in cases where little training information is available to support performance i.e. learning by practice. Recognising incorrect plans can be an extremely difficult job, particularly when trainees have developed new methods which are beyond a set of well-established ones available to the interpreter.

All these aspects of performance were very prominent in the analysis of the recorded actions, and various examples will be cited in the following sections. To overcome these problems, verbal protocols were collected during the actual plant operation and were utilised in the analysis. It will be recalled that, in order to minimise any interference with the primary task, trainees were asked to state the goal they were pursuing, only in those cases that these were not very clear to the experimenter. The HTA of the task was an invaluable tool in aiding the experimenter to hypothesise a small set of plausible goals and plans, and thus, avoid excessive probing and questioning. Incoming information - that is, observation of trainees actions and statements - was first attempted to 'fit' into maintained hypotheses in order to confirm one of them. If this was not the case, a new set of hypotheses was formed and the same understanding process was re-applied.
Maintaining a set of hypotheses about plausible goals and plans during the whole experiment would be an impossible job, if not for the support of the HTA of the task. It is worth noting that the goal-structure of the task, as it is specified in the HTA, provided a basis for relating various plausible goals under the framework of a superordinate goal, and this has facilitated the process of keeping trace of and revising existing hypotheses.

During the actual plant operation, an additional effort was made to record trainees' knowledge of goal-interactions and misconceptions about 'the way-the-plant-works'. Any comments on the part of the trainees regarding ways of sequencing interacting goals, were recorded for subsequent analysis; misconceptions about the functioning of the plant were manifested in various ways such as development of incorrect plans and trial-and-error strategies.

A third source of information about these aspects of performance was the questionnaire and the informal interview in the end of the experiment, which required trainees to describe the strategy they had followed in the performance of the transfer task. Although a post hoc description of the behaviour may not correspond to the way operators do 'things' under the time and effort constraints of the actual situation, it has provided useful information which could not be acquired otherwise e.g. thoughts trainees had but could not report even when prompted or thoughts they had considered to be rather 'foolish'.

Another important aspect of the interview was to record the criteria used by trainees in order to choose among alternative courses of action. The criteria employed can include:

- one choice may involve a higher cognitive load than another. Thus, trainees occasionally do things the easy way although they appear to know the proper one. For example, some trainees have avoided time-sharing two interacting goals although they seemed to know the kind of interaction involved.

- one choice may be more 'efficient' than another in terms of speed or accuracy or economy of operation.

- one choice may be seen as more 'risky' than another, possibly based on previous experience with the same task.
- some choices may reflect misconceptions about trainees conceptual knowledge of the plant.

The issue of plan recognition is very important for the development of Intelligent Tutoring Systems. It is conceivable that the selection of the next task element to be mastered and the appropriate form of extrinsic information will require an understanding of the knowledge the trainee brings to the present task. Recognising the types of plans evolved by trainees is one source of gaining such information. A number of Artificial Intelligent programs have already been reported in the literature - i.e. ADVISOR (Genesereth, 1982), POISE (Carver et al., 1984), PAM (Wilensky, 1983), BUGGY (Brown and Burton, 1978) - which have made some progress towards the formalisation of the plan recognition process. However, this issue is a very complicated one, and research needs to expand beyond the study of human behaviour in these 'micro-worlds' to the performance in complex process environments.

ANALYSIS OF A SAMPLE OF RECORDS OF ACHIEVEMENT

In order to illustrate the adopted approach to the process of plan recognition as well as the contribution of the HTA of the task, a number of records of achievement will be presented in this section. The performance of two subjects on the original task (trial-2) and three other subjects on the transfer task (trial-4) will be considered in detail, as these subjects were felt to fairly-well reflect the strategies adopted by the procedures-, analysis- and model-groups. Because the former two groups did not differ significantly in the performance of the original task, only the performance of the procedures-group on the original task will be presented.

The performance of the practice-group in both tasks was characterised by large individual differences, with trainees adopting remarkably different strategies which could cover the whole spectrum of strategies of the other groups; thus, the performance of this group will be described with reference to the other groups only.

In order to relate the goals and plans developed by different trainees, the HTA of both tasks will be used as a reference point. The HTA of the transfer
task in figure 9.1, can indicate the way the procedures- and analysis- groups would be expected to perform the task, in order to achieve a high degree of transfer.

Performance at the original task

The procedures- and analysis- groups

The control actions taken by subject-1 (S1) of the procedures-group are displayed in table 9.1, and are considered to be representative of the way the procedures- and analysis- groups performed the original task. The first column describes the state of the plant which can be changed by adjusting the positions of the five valves which are shown in the second column. In order to make a concise description, parameters which remained constant during a trial would not be displayed e.g. rates of feedflow, reflux flow, and the position of the reflux valve.

A good method to interpret the control actions is to relate them to the HTA of the task in a bottom-up scanning, so that the various goals and plans are examined in the following order:

- goal-1 (adjust the level in the column by controlling valves Vi and Vo);
- goal-2 (establish product qualities by controlling valves Vb, Vc, and Vd);
- goal-3 (adjust the level in the drum by controlling valve Vd);
- methods for sequencing goals 1 and 2 (by controlling valves Vo and Vb); and,
- the overall plan.

The number of production runs can also be used as an index of the state of the plant (indicated by the symbol 'F' in table 9.1). The three intermediate goals that trainees may be pursuing at any stage are presented in the last column (see G1, G2, and G3 in table 9.1), as these have been inferred from the analysis of the verbal protocols. In order to indicate possible trainees intentions, a number of abbreviations were used such as:

- S: stabilising the level in the column or drum;
- A: making the level accurate, regardless of its degree of stability;
Figure 9.1. Task description for the transfer task.
Table 9.1.
Control actions of subject S1 of the procedures-group at the original task.

<table>
<thead>
<tr>
<th>System-state</th>
<th>Action</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIC1 FR3 Xb PI5 TI5 LIC11 FR11 Xd</td>
<td>Vi Vo Vb Vc Vd</td>
<td>G1 G2 G3</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0</td>
<td>25 0 0 0 0 1</td>
<td></td>
</tr>
<tr>
<td>1 0 30 915 25 0 0 30</td>
<td>99 0 0 0 0</td>
<td>2</td>
</tr>
<tr>
<td>25 0 30 979 25 0 0 30</td>
<td>25 0 0 0 0</td>
<td>7</td>
</tr>
<tr>
<td>26 0 30 979 25 0 0 30</td>
<td>25 20 0 0 0</td>
<td>8</td>
</tr>
<tr>
<td>29 1187 30 1034 25 0 0 30</td>
<td>25 30 0 0 0</td>
<td>12</td>
</tr>
<tr>
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<td>25 40 0 0 0</td>
<td>15</td>
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<td>25 50 0 0 0</td>
<td>17</td>
</tr>
<tr>
<td>32 2967 30 1034 25 0 0 30</td>
<td>25 55 0 0 0</td>
<td>24</td>
</tr>
<tr>
<td>31 3264 30 1034 25 0 0 30</td>
<td>25 53 0 0 0</td>
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</tr>
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<td>32 3145 30 1034 25 0 0 30</td>
<td>25 54 0 0 0</td>
<td>39</td>
</tr>
<tr>
<td>32 3205 30 1034 25 0 0 30</td>
<td>25 54 20 20 0</td>
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</tr>
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</tr>
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<td>32 2221 21 1242 79 14 0 55</td>
<td>25 54 85 85 0</td>
<td>63</td>
</tr>
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<td>32 2221 21 1248 79 17 0 54</td>
<td>25 54 85 85 99 65</td>
<td></td>
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<td>31 2221 21 1240 79 12 0 51</td>
<td>25 54 85 85 70 83</td>
<td></td>
</tr>
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<td>31 2221 21 1250 79 16 954 50</td>
<td>25 54 85 85 60 98</td>
<td></td>
</tr>
<tr>
<td>31 2221 21 1250 79 16 954 50</td>
<td>25 54 85 85 60 99</td>
<td></td>
</tr>
</tbody>
</table>
- T: adjusting the level on the target value, after it had been stabilised in a
certain position (tuning);

- SA: uncertainty whether S or A is the case;

- E: execution errors, which are recovered by trainees in due course;

- F: flushing out the level-I in the drum;

- D: disturbing already established bottom product qualities, caused by
  inappropriate manipulations.

From table 9.1, it appears that S1 concentrated on goal-1 initially and spent the
first 45 'runs' in filling the level in the column above the limit of 20 cm, and
then stabilised it at 32 cm (see F45, or frame no. 45) by returning valve Vi to
its original position and by increasing valve Vo gradually.

When goal-1 was achieved, S1 focused on goal-2, manipulating valves Vb and Vc
at the same time. He started 'flushing out' the level in the drum (F65) when
the composition of the bottom product was achieved (that is, Xb=21%) and the
composition of the top product (Xd) was on its way to the target value.
When he was asked to justify this course of action, he explained that he
expected Xd to reach the target since Xb had already been there, and that the
amount of liquid collected in the drum so far (that is, 17 cm) would not allow
him to confirm it. This would explain the fact that he spent so many 'runs'
(F65-F83) in 'flushing out' level-I, in contrast to other subjects of the same
group who started this operation before Xb approached its target value. It
appears then, that a few subjects from both the procedures- and analysis-
groups carried out plan-5.2 (figure 7.1) as a contingent sequence plan rather
than as an integrating one, since they seemed to have understood the 'one-to-
one' mapping relationship between the product compositions.

When the top product quality (Xd) was almost achieved (F83), S1 started goal-3
by adjusting Vo at 70; level-I stabilised at 11 cm (F93), at which point S1
closed valve Vd in order to tune the level on target and stabilised it later on
(F96) by returning Vd to the target value which had previously been found.
Both goals 1 and 3 were achieved with the effective plans 5.1 and 6 which
were given to S1 in the training situation.
Considering the way that goals 1 and 2 were sequenced, it can clearly be seen that a fixed sequence plan was employed; the same was true for the overall plan-B. A prominent feature of the performance of the procedures-group is that the process was driven through a number of steady states, where the criterion for proceeding with the next goal was the completion of the previous one. Although, this can be seen as a feature of efficient performance, it may give trainees little opportunity to see the process in many transient states and thus, practise diagnostic and compensatory skills.

The model-group

Two subjects of the model-group appeared to have developed strategies similar to those adopted by the procedures- and analysis-groups; however, the other five subjects performed the original task in a consistent manner, which is represented by the performance of subject-2.

The same scanning approach will be applied to the performance of S2 (table 9.2). S2 spent 12 'runs' in adjusting goal-1 (F12), until the level in the column reached the target; then he started time-sharing goals 1 and 2. A 'rule of thumb' evolved by many subjects of the model- and practice- groups was that 'in order to get a feel for the rate at which a level is falling or rising, the output valve should be adjusted at the average position of 50'; in this way, the search space for the target position of this valve is reduced to the upper or lower half of the 0-100 interval. This was the case for S2, as it can be seen from frame F7. When S2 started time-sharing the two goals (F12), he made two execution errors by trying to stabilise the level close to the target; specifically, he reduced Vo (F10 and F19) when level-1 was rising. When he realised his error (F22), the level in the column had reached 34 cm. In the following frames (F22 to F35), he increased Vo in large steps in order to bring the level closer to the target (F35).

Although, from his previous experience, the level was not stable with Vo=40, he returned Vo to this position at F35; again, because he seems to have given priority to bringing the level closer to the target rather than stabilising it, he increased Vo (F41, F42) in large steps. From this point onwards, he adjusted Vo in steps of 5 in order to achieve a steady level (F44 to F51).
Table 9.2.
Control actions of subject S2 of the model-group at the original task.

<table>
<thead>
<tr>
<th>System-state</th>
<th>Action</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIC1 FR3 Xb PI5 TI5 LIC11 FR11 Xd</td>
<td>Vi Vo Vb Vc Vd F</td>
<td>G1 G2 G3</td>
</tr>
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<tr>
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<td>99 0 0 0 0 2</td>
<td></td>
</tr>
<tr>
<td>25 0 30 979 25 0 0 30</td>
<td>99 50 0 0 0 7</td>
<td></td>
</tr>
<tr>
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<td>25 40 0 0 0 8</td>
<td></td>
</tr>
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<td>25 37 0 0 0 10</td>
<td></td>
</tr>
<tr>
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<td>25 38 20 20 0 12</td>
<td></td>
</tr>
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<td>25 40 30 20 0 16</td>
<td></td>
</tr>
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<td>25 30 40 40 0 19</td>
<td></td>
</tr>
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<td>25 49 40 40 0 22</td>
<td></td>
</tr>
<tr>
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<td>25 60 55 40 0 25</td>
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</tr>
<tr>
<td>33 3116 26 1219 73 7 0 58</td>
<td>25 70 60 40 0 28</td>
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</tr>
<tr>
<td>32 3493 25 1794 74 9 0 57</td>
<td>25 70 60 80 0 31</td>
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<td>31 3493 25 1436 74 13 0 57</td>
<td>25 40 40 50 30 35</td>
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<td>25 40 50 65 60 39</td>
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<tr>
<td>33 1910 24 1441 75 12 954 56</td>
<td>25 99 60 65 60 41</td>
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<td>32 5319 27 1427 72 11 954 57</td>
<td>25 70 70 65 60 42</td>
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</tr>
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<td>31 3343 24 1438 75 11 954 56</td>
<td>25 45 65 70 60 44</td>
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</tr>
<tr>
<td>32 2066 23 1443 77 9 954 56</td>
<td>25 50 70 75 60 47</td>
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</tr>
<tr>
<td>32 2295 23 1439 77 7 954 55</td>
<td>25 55 75 75 60 51</td>
<td></td>
</tr>
<tr>
<td>32 2398 22 1440 78 6 954 53</td>
<td>25 55 78 78 50 56</td>
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</tr>
<tr>
<td>32 2525 23 1436 77 6 795 54</td>
<td>25 60 80 78 50 61</td>
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</tr>
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<td>25 50 80 78 50 72</td>
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<tr>
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<td>25 50 83 85 50 74</td>
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</tr>
<tr>
<td>31 2180 22 1440 78 6 795 53</td>
<td>25 50 83 85 50 77</td>
<td></td>
</tr>
</tbody>
</table>
Table 9.2 (continued)

| L1C1 | FR3 | Xb | P15 | T15 | L1C1 | FR11 | Xd | Vi | Vo | Vb | Vc | Vd | P1 | G1 | G2 | G3 |
|------|-----|----|-----|-----|------|------|----|----|----|----|----|----|----|----|----|
| 31   | 2057| 21 | 1444| 79  | 7    | 795  | 52 | 25 | 50 | 80 | 85 | 50 | 79 |    |    |    |
| 31   | 2180| 22 | 1440| 78  | 7    | 795  | 52 | 25 | 50 | 82 | 85 | 50 | 81 |    |    |    |
| 31   | 2180| 22 | 1440| 78  | 7    | 795  | 52 | 25 | 55 | 82 | 85 | 50 | 83 |    |    |    |
| 31   | 2398| 22 | 1440| 78  | 7    | 795  | 52 | 25 | 55 | 84 | 85 | 50 | 84 |    |    |    |
| 31   | 2262| 21 | 1448| 79  | 9    | 795  | 51 | 25 | 55 | 84 | 90 | 50 | 90 |    |    |    |
| 31   | 2262| 21 | 1450| 79  | 10   | 795  | 51 | 25 | 80 | 84 | 90 | 5  | 93 |    |    |    |
| 30   | 3820| 24 | 1435| 75  | 11   | 79   | 51 | 25 | 55 | 84 | 90 | 5  | 94 |    |    |    |
| 30   | 2262| 21 | 1459| 79  | 16   | 79   | 51 | 25 | 55 | 84 | 90 | 55 | 97 |    |    |    |
| 30   | 2262| 21 | 1464| 79  | 16   | 874  | 51 | 25 | 55 | 84 | 85 | 60 | 101|    |    |    |
| 30   | 2262| 21 | 1464| 79  | 16   | 954  | 51 | 25 | 55 | 84 | 80 | 60 | 103|    |    |    |
| 30   | 2262| 21 | 1465| 79  | 17   | 954  | 51 | 25 | 55 | 84 | 80 | 90 | 105|    |    |    |
| 30   | 2262| 21 | 1465| 79  | 16   | 1431 | 51 | 25 | 55 | 84 | 83 | 63 | 106|    |    |    |
| 30   | 2262| 21 | 1462| 79  | 15   | 1033 | 50 | 25 | 55 | 84 | 83 | 63 | 118|    |    |    |
Further attempts to bring the level at 30 cm (F61 to F70) in conjunction with the adjustment of \( V_b \) and \( V_c \) to achieve goal-2, seem to have distracted him from the fact that the target position of \( V_o \) had already been found at F56 to be \( V_o=55 \) (see also final position at F118). The following frames were spent trying out other positions of \( V_o \), until \( V_o=55 \) was rediscovered at F83. In the end, the level was tuned at F93 and F94.

The plan adopted to achieve goal-1 can be summarised as follows:

- **step-1:** bring level close to target with maximum feedflow (accurate level);
- **step-2:** keep level relatively steady, by adjusting \( V_o \) only (stable level);
- **step-3:** maintain level within limits of tolerance, by adjusting \( V_o \) in large steps (accurate level);
- **step-4:** repeat from step-2 until level is stable on its target value.

This plan is less efficient than the one adopted by S1, in which the target position of \( V_o \) was found first, by getting the level stable at any position and then tuning it to be on target.

Goal-2 was first attempted at frames F12, F16 and F19, where another 'rule of thumb' was evolved similar to the one given to the procedures-group, namely, 'in order to condense the produced vapours fully, the flows of the cooling and heating agents should be adjusted at similar rates'. However, this plan was not followed consistently all over the trial, and an excessive amount of vapours was produced (\( V_b \) was increased to 60, whilst \( V_c \) was kept constant at F28) which increased the pressure beyond the specified limit of 1.5 at. (F31). S2 relieved the pressure by increasing the flow of the cooling agent (F31) and reducing the overall vapour production later on (F35). From this point onwards, S2 tried to achieve goal-2, minimising the overall energy consumption.

He adjusted \( V_d \) for the first time at F35, and subsequently he increased it to 60 where he kept it for 17 'runs' (F39 to F56). A number of hypotheses can equally be plausible such as 'S2 is trying to get a 'feel' for the flow-rate FR11' or 'he is flushing out the level-11' or 'he has suspended execution of this goal'. It is only from the verbal protocols where the second hypothesis was confirmed. When level-11 was just above the height of the exit pipeline which carries the top product (that is, 5 cm), S2 tried to stabilise the level at a low position (F56 to F74) so that a good estimate of the composition \( X_d \) could be
obtained. Up to F74, S2 adjusted Vd as part of his strategy to achieve the product qualities rather than establish level-I. At F93, S2 closed Vd in order to bring level-I close to target, although he had not found the target position of Vd yet. As he understood that Vd should be adjusted at a position greater than 50 (F97), he increased Vd until the level became steady at 16 cm (F103). Then, he brought the level closer to the target by adjusting Vd fully open (F105), and subsequently he adjusted Vd at 63 which he expected to be the target position. The trial terminated at F118, where all targets had been achieved and level-I remained within its limits of tolerance for at least three 'runs', with Vd equal to 60 (±3) units. Goal-3 may be seen to have been achieved with a similar strategy to goal-1, and in both cases the plan was suboptimal.

All over the trial, S2 appeared to time-share goals 1 and 2, although he was not entirely consistent; for instance, he disturbed the composition of the bottom product (F25, F42, and F94) by either failing to adjust Vb in combination with Vo or increasing Vo disproportionately largely (i.e. Vo=99 at F41). Time-sharing plans require a good knowledge of the size of effects in addition to goal-relationships, which is difficult to master in the initial stage of learning. Finally, the overall plan can be seen as a fixed sequence type, with the level-I receiving intensive attention as such at F93, where the product qualities had almost been established.

Performance at the transfer task

The procedures-group

Another subject (S3) of the procedures-group was selected for the analysis of his performance at the transfer task.

From table 9.3, it can be seen that the first 50 frames were used by the experimenter to achieve the intermediate stage of distillation, from which point onwards S3 took over the task of establishing the final stage, with the time-base being adjusted at the slow mode.

After the plant had been running for approximately 10 frames (F51 to F62), S3 adjusted Vo at 45; the indication SA implies that it is difficult to judge whether S3 intended to stabilise the level-I or bring it on target. At F77, he
Table 9.3.

Control actions of subject S3 of the procedures-group at the transfer task.

<table>
<thead>
<tr>
<th>System-state</th>
<th>Action</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
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<td>Vi Vo Vb Vc Vd P</td>
<td>G1 G2 G3</td>
</tr>
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Table 9.3 (continued)

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<th>System-state</th>
<th>Action</th>
<th>Goals</th>
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<td>Pi5 Ti5 LIC11 FR11 Xd</td>
<td>Vi Vo Vb Vc Vd F G1 G2 G3</td>
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<tr>
<td>30 1929 21 1446 81 15 455 68</td>
<td>20 43 88 90 38 158</td>
<td></td>
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</table>
increased \( V_o \) to 50 in order to make the level more accurate. Indeed, he managed it at F80, but he left \( V_o \) at the same position for quite a long time and the level fell to 28 cm (F92); again, it is not possible to establish whether the intention was to get a 'feel' for the rate of change of the level or this goal had been suspended temporarily. As he was mainly concerned with keeping the level accurate rather than stable, he returned \( V_o \) to 45 (F92), without noticing that the level was falling at this position (see previous F62); as a matter of fact, this occurred at F115.

It is worth noting that, at this point (F115), most of the parameters were very close to their targets, apart from level-1 which was drifting downwards very slowly; the next expected action was to adjust \( V_o \) between 40 and 45 in order to find the target value of \( V_o \). However, S3 has modified his plans and reduced \( V_o \) to 35 in order to bring the level on target gradually, through frames F115 to F129. Then he tried to stabilise the level with \( V_o \) at 40 (F132); unfortunately, the level rose to 32 cm and S3 increased \( V_o \) to bring it back on target (F137). At F150, he realised that the target position of \( V_o \) should lie between 40 and 45, and adjusted it at 43 which maintained the level steady for the rest of the trial.

It is clear that S3 has changed his plans for adjusting goal-1, and instead of finding the position of \( V_o \) which would stabilise the level (F115), he spent another 40 'runs' in trying to make it accurate first and then steady (F115 to F155). This a case of sub-optimal transfer, in which the trainee failed to recognise the relevance of an efficient plan to a new context. His particular plan can be summarised as follows:

- **step-1:** bring level close to target (accurate level);
- **step-2:** keep level relatively steady, by adjusting \( V_o \) only (stable level);
- **step-3:** maintain level within limits of tolerance, by allowing it to gradually drift downwards or upwards (accurate level);
- **step-4:** repeat from step-2 until level is stable on its target value.

Goal-2 was carried out according to the plan taught in the original task, however an execution error occurred at F117, which was recovered in the following intervention. The change in strategy in achieving goal-1 had a detrimental effect on goal-2; although, S2 achieved the product qualities at F115 by having previously adjusted \( V_o \), \( V_b \) and \( V_c \) at their target values (F112), he had to spent another 35 'runs' (F115 to F150) in chasing \( V_b \) and \( V_c \).
in order to maintain qualities on target while he was trying to achieve goal-1 with a sub-optimal plan.

In order to bring level-I
target (goal-3), Vo was closed until frame F83 was reached, where the rule of thumb of 'adjusting Vd at 50' was discovered. Although, there was no need to flush out the level-I in drum when the product qualities were on target (F87), S3 adjusted Vd fully open and then reduced it to 40 in order to keep the level steady. In his attempt to stabilise the level (F90 to F105) he made an execution error (that is, Vd=99 at F102) which was immediately rectified. Although, the new position of Vd (that is, Vd=40 at F105) could not keep the level steady, S3 rushed to bring it back on target by closing Vd (F110 to F112); later on, he realised that the target position of Vd should be less than 40, and tried it out at F115. Unfortunately, it was not easy to estimate the target Vd because the total liquid production in the drum was affected by the valve positions of Vo, Vb and Vc; S3 was desperately trying to keep level-I steady by reducing Vd to 20 (F129), however there was no point in doing so, since the rate of liquid production was changing continuously. When all valves were adjusted close to their target values (F137), S3 started 'chasing' level-I by gradually increasing Vd from 20 to 40 (F141 to F150), since he could not recall that Vd should be adjusted between 35 and 40 (see previous F105, F115). In the end, he found the target Vd at F155.

Setting as a priority criterion to achieve an accurate level rather than a stable one, was a major departure from the efficient plan-6 (figure 9.1) that S3 was taught in the original task. The plan developed to achieve goal-3 has certain similarities with the plan developed by S2; however, S2 had developed such a plan without any explicit support from his training method, whereas S3 had already been provided with such a plan but could not see how it could be applied to the new transfer situation. This is clearly a case of sub-optimal transfer, where some response has been constructed for goal-3, however this is not the optimal one.

Goals 1 and 2 were sequenced with a fixed cycle plan, in which goal-2 was attempted when some progress had been made towards goal-1 which was paid further attention when some progress had been made with goal-2. At F77, however, it might appear that S3 was time-sharing these goals, but he was mainly concerned with goal-2 and was performing goal-1 incidentally as he was first keying in Vc, then Vb, and then Vo. Fixed cycle plans can be effective,
when valve \( V_0 \) (affecting both goals 1 and 2) is adjusted in small steps so that any side-effects are minimised. If this is not the case, a fixed cycle plan can become a 'vicious circle', when goal-2 is attended because it has been disturbed by previous adjustments of goal-1 (i.e. \( F_67, F_94, F_{117}, \) and \( F_{134} \)) and not as part of a pre-planned course of action. The overall plan was of a fixed cycle type which was carried out quite effectively all over the trial, but it became of little importance to the overall task, when \( S_3 \) made a significant deviation from the strategy he had been taught in the original task (\( F_{112} \) and \( F_{115} \)). In the following record, we shall see how such a type of plan can also be used to do the job effectively.

The analysis-group

In contrast to the procedures-group, most of the subjects of the analysis-group recognised the similarities of the new context to the original task, and applied their plans effectively. Subject \( S_4 \) of the analysis-group was selected because he demonstrated in a clear manner the way that his old plans transferred to the new situation.

From table 9.4, it can be seen that \( S_4 \) was primarily concerned with stabilising level-1 at any position first, and subsequently tuning it on target. To achieve this, he adjusted \( V_0 \) in small steps (that is, less than 5 units) while monitoring any changes in the level. Specifically, \( V_0 \) was adjusted at 38 (\( F_{57} \)) and maintained there for 11 runs (that is, up to \( F_{68} \)) until level-1 was substantially increased to 33 cm; then, \( V_0 \) was adjusted at 42 (\( F_{71} \)) in order to keep the rising level steady. As \( S_4 \) was very much concerned with level stability, he noticed a small rise in the level recorder and he further increased \( V_0 \) to 45 (\( F_{88} \)). Since the level appeared to be relatively steady (\( F_{88}-F_{105} \)) he decided to provoke it by slightly decreasing \( V_0 \) to 44 (\( F_{105} \)). Continuous monitoring of the level enabled him to detect a further 'shift downwards' (\( F_{113} \)) at which point he decreased \( V_0 \) to 43 which was the target position, as it can be seen from the last frame \( F_{129} \). However, because the level was above the target he adjusted \( V_i \) (\( F_{117} \) to \( F_{125} \)) in order to tune it. This was a clear example of a subject whose priority was the stability rather than accuracy of the level.

Goal-2 was first attempted at \( F_{64} \), where \( S_4 \) detected a disturbance in the composition of the bottom product (\( X_b \)); he rectified it by adjusting \( V_b \) and \( V_c \) simultaneously at \( F_{71} \). The same strategy was re-applied to any disturbance
Table 9.4.

Control actions of subject S4 of the analysis-group at the transfer task.

<table>
<thead>
<tr>
<th>System-state</th>
<th>Action</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIC1 FR3 Xb PI5 TI5 LIC11 FR11 Xd</td>
<td>Vi Vo Vb Vc Vd P</td>
<td>G1 G2 G3</td>
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<td>30 1650 21 1236 79 15 729 50</td>
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<td></td>
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<tr>
<td>31 1651 21 1219 77 9 729 57</td>
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<tr>
<td>32 1903 22 1209 75 6 495 65</td>
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<tr>
<td>32 1905 22 1204 75 5 470 69</td>
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<td>33 1692 21 1210 76 7 0 70</td>
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<tr>
<td>33 1901 22 1210 75 8 0 71</td>
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<tr>
<td>33 1876 21 1223 77 12 0 69</td>
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<td></td>
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<tr>
<td>33 1877 21 1223 76 13 247 68</td>
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<tr>
<td>33 1878 21 1224 76 14 247 68</td>
<td></td>
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<tr>
<td>33 1879 21 1228 77 15 371 68</td>
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<tr>
<td>33 2016 21 1228 77 15 371 69</td>
<td>S</td>
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<tr>
<td>33 2017 21 1226 76 15 433 68</td>
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<tr>
<td>33 2017 21 1230 77 16 433 68</td>
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<tr>
<td>33 2100 22 1224 75 15 495 68</td>
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<td>33 1974 21 1226 76 15 495 68</td>
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<td>32 1974 21 1229 77 15 470 68</td>
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<td>32 1797 20 1229 77 15 470 67</td>
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<tr>
<td>32 1929 21 1227 76 15 470 68</td>
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<td>30 1933 21 1225 76 15 470 68</td>
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<tr>
<td>30 1933 21 1225 76 14 470 68</td>
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</table>
of $X_b$ caused by previous manipulation of $V_o$. However, these disturbances were not marked on his record in table 9.4, since they cannot be foreseen when $V_o$ is adjusted in steps less than five units. Although $S_4$ could have time-shared manipulation of valves $V_o$ and $V_b$ to avoid such disturbances, his control performance was high enough because these were kept to a minimum. When $S_4$ managed to achieve both product qualities as well as stabilise level-11 ($F_{116}$), he subsequently adjusted $V_i$ to tune level-1, avoiding any side-effects to goal-2. It is clear then, that when goals 1 and 2 are sequenced with a fixed cycle plan and manipulation of $V_o$ is done in small steps, control performance is maintained at high levels. Indeed, $S_4$ had the second best control performance of all subjects.

When the reflux valve $V_r$ was adjusted at 60 ($F_{51}$), level-11 dropped drastically to low values ($F_{57}$) and $S_4$ tried to stabilise it for the rest of the time (up to $F_{68}$). Because the level was a few centimeters only above its lower limit (that is, 5cm), $S_4$ decided to close $V_d$ completely and bring the level to 12 cm ($F_{68}$ to $F_{77}$). This was a modification of the plan he had been taught in the original task, namely that 'level-11 should be flushed out' in order to enable a better estimate of the current quality of the top product ($X_d$) to be obtained. It was obvious that $S_4$ was concerned with achieving goal-3 for its own sake rather than use it to serve goal-2. When $S_4$ was interviewed in the end of the experiment, he revealed a rule of thumb which he developed from his experience with the original task.

Specifically, he argued that 'when the composition of the bottom product is achieved, the composition of the top product will be on-target although this might not be possible to confirm from the display'; therefore, the step of 'flushing out level-11' could be omitted since the true composition of $X_d$ would appear on the display shortly; in the meantime he could make some progress towards stabilising level-11. As a matter of fact, both product qualities were achieved at $F_{77}$ when he decided to rise level-11. Later on, he adjusted $V_d$ at 30 ($F_{83}$) and then at 35 ($F_{93}$) as level-11 was rising; when he found that the value of 40 ($F_{107}$) decreased level-11, he adjusted $V_d$ at 38 ($F_{110}$) which was its target value. It can be seen then, that experience with the original task may enable subjects to evolve 'rules of thumb' which may modify the plans they were originally taught and develop strategies which are very effective. The main criterion, however, still remains that the level should be stabilised before any effort is made to fix it on target.
With regard to the overall plan employed, it seems that S4 carried it out as a fixed cycle type by making some progress towards goals 1 and 2 and subsequently carrying out a chunk of goal-3. The conversion of the fixed sequence plan, he had originally been taught, to a fixed cycle type can be seen as the result of the previously described 'rule of thumb'. Therefore, S4 achieved a good performance by improving some of his plans, although the old ones could fairly well be applied to the new situation.

The model-group

The subjects of the model-group were supported in their performance by a model of the functioning of the plant, however, they had to develop their own plans to achieve the three sub-goals as well as the overall goal. An analysis of their records of achievement of the original task showed that only some of them managed to develop such efficient plans as the ones given to the procedures- and analysis-groups; hence, their inferior performance to these groups on the original task. Nevertheless, as far as subjects of the model-group maintain or improve their plans, this can be considered as an instance of positive transfer. Negative transfer will refer to cases where plans applied to the new context are less efficient than the ones developed in the original situation. This was the case for subject S5 who modified a set of efficient plans developed in the context of the original task.

From table 9.5, it may be seen that S5 attended to goal-1 as soon as level-1 rose to 31 cm (F60); he responded to further rising of level-1 by increasing Vo to 40 (F63). He kept increasing Vo in small steps, although level-1 appeared to be steady; it is difficult to establish whether his intention was to stabilise the level or make it accurate, at this particular point. However, as he further increased Vo to 50 (F69) it is reasonable to assume that he wanted to bring the level back on target. Curiously enough, S5 maintained Vo at the same position, although it was clear that level-1 was drastically falling (F69 to F83). When the level fell to 28 cm (F87), he decided to reduce Vo to 35 (F96) although level-1 appeared to be steady with Vo between 40 and 48.

As he seemed to be concerned with the accuracy rather than stability of level-1, he waited until the level approached the target (F105). Subsequently, he tried to stabilise it by setting Vo back at 40 (F110) and then 45 (F112). The
Table 9.5.

Control actions of subject S5 of the model-group at the transfer task.

<table>
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<th>System-state</th>
<th>Action</th>
<th>Goals</th>
</tr>
</thead>
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<td>G1 G2 G3</td>
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Table 9.5 (continued)

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<th>System-state</th>
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<th>Goals</th>
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<tbody>
<tr>
<td>LIC1 FR3 Xb PI5 TI5 LIC11 FR11 Xd</td>
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</tr>
<tr>
<td>30 1935 21 1778 88 15 470 67</td>
<td>20 43 88 99 38 133</td>
<td></td>
</tr>
</tbody>
</table>
level appeared to be relatively steady and a final adjustment of Vo at 43 stabilised it on target (F126). It is worth noting that S5 had a different priority criterion during the original task which produced a more efficient plan for goal-1, similar to the plans given to the procedures-group. It is not clear whether this plan modification was the result of continuous experimentation with the process or an illustration of the fact that plant theory was not sufficient to enable S5 to develop efficient plans. A post hoc explanation is that plant theory has stimulated S5 to try out alternative plans, but he actually needed more experience with the plant in order to reside with the more efficient ones. Fortunately, the case of S5 was the only instance of negative transfer in the model-group, whilst the other subjects either re-applied their existing plans or improved them in the new context. This issue, however, will be elaborated further in the next chapter.

Goal-2 was carried out at the same time with goal-1, in order to cancel out any side-effects from previous manipulations. Most of the time, Vb was adjusted in combination with Vo as it can be seen from the interval F60 to F69. Although S5 managed to develop a time-sharing plan for carrying out goals 1 and 2, he overshot the pressure at 2.4 at. (F74), by adjusting Vb disproportionately to Vc; in order to relieve the pressure, he decreased Vb drastically although he was aware of the consequences upon the established bottom product quality. Because of this fact, his record will not be marked with a 'D', as the main emphasis was placed upon disturbances or side-effects which were not intended.

A reasonable question then is 'why S5 overshot the pressure'; was it because he had not grasped the idea that the pressure and temperature are related to the amount of vapour enclosed in the column and therefore, amount of heat supplied and removed through the flows of the heating and cooling agents or because he had been inconsistent in that particular point in time. The interview in the end of the trial provided support for the second hypothesis. For the rest of the trial, S5 was pre-occupied with high pressure profiles and took no chances for it, so he increased Vc fully open as he tried to adjust the heat supply and bring the composition of the bottom product back on target (F98 to F117).

Goal-3 was first attempted, when level-II fell to 11 cm and S5 adjusted Vd at 45 (F55); it was difficult, however, to establish whether he set as a priority criterion the stability or accuracy of the level-II. As he drastically reduced
Vo to 5 (F67) when the level was well above the lower limit of 5 cm, we can assume that he was concerned with accuracy. At F87, level-I I was brought on target and an effort was made to keep it steady by setting Vd at 25. At the following frames, S5 suspended execution of goal-3 as he was continuously changing Vo, Vb and Vc, and thus, liquid production in the drum. Although he shifted his criterion to level stability at F115 and F122, he became very concerned with accuracy and opened Vd fully at F126. Again, S5 developed a more efficient plan for this goal at the original task, but transferred it negatively to the new context. The previous argument made for goal-1 holds for goal-3 as well.

Goals 1 and 2 were sequenced through a time-sharing plan which did not produce excessive side-effects. Definitely, S5 has not completely mastered the dynamics of the plant, since he could not estimate the right size of adjustment for valves Vo and Vb and thus, he had a much lower score of control performance than S4. Time-sharing plans make certain demands about knowledge of plant dynamics, and unless the trainee is a bit 'conservative' in the size of valve adjustments, these plans would require a high degree of practice if they are going to completely cancel out any side-effects on goal-2.

However, S5 was not entirely consistent, and he converted this plan into a fixed cycle type (e.g. F87, F98). This is another important aspect of many analysed records, where subjects appeared to change over between plans at different points, although they may have carried them out in one particular form in the majority of their interventions. In the next chapter we shall examine the types of plans which converted into other types as well as their implications for the definition of the plan taxonomy. The overall plan was carried out as a fixed cycle plan in the majority of the situations.

FACTORS AFFECTING TRANSFER OF TASK ELEMENTS IN FLEXIBLE COGNITIVE SKILLS

From the complete analysis of the collected records of achievement, it appeared that a number of factors have considerably affected the size of transfer of task elements in the final stage of distillation. The three factors identified in the analysis concern the mapping relationships between system prototypes and plans, the role of planning elements and rules of thumb, and
the role of system or task complexity. Each of these factors will be considered in greater detail in this section.

Mapping relationships between system prototypes and plans

From the analysis of the previous sample of records of achievement, it may appear that the same goal can be achieved by a variety of plans which can range from effective through to sub-optimal to ineffective ones. For instance, goal-1 was achieved in three different ways by S1 and S4, by S2, and by S3 and S5; whereas the theory behind this goal can be summarised into a system prototype consisting of a process parameter (that is, the level) with one input and one output, a number of plans were developed to achieve it. In this section, we shall examine this 'one-to-many mapping' relationship between system prototypes and plans in a greater detail, since this has important implications for the transfer of task elements. Specifically, we shall examine different ways of achieving goals 1 and 3 as well as goal-2.

System prototypes and strategies for achieving goals 1 and 3

Goals 1 and 3 have to do with 'establishing a steady level either in the column or in the drum on a given target value'. Therefore, the same strategies are applicable to both goals, although goal-3 is usually achieved by adjusting only the output flow of the level in contrast to goal-1, in which both the input and output flows of the level can be adjusted.

We can assume that the kind of system prototype of a level that most trainees have in mind may consist of a process parameter i.e. the level, controlled by manipulations of input and output flows.

However, as it can be seen from table 9.6, five different strategies were developed by trainees as well as the 'experts' who participated in the pilot study in order to achieve goals 1 and 3. The second strategy was mainly developed by the 'experts', and it is reported here for the completeness of the matter of skill flexibility.
### Table 9.6. Strategies for achieving goal-1.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Steps</th>
</tr>
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</table>
| **A1**   | Step-1: Achieve a steady level at any position by gradually increasing Vo and maintaining Vi on the target value (stability);  
Step-2: Bring level on target by adjusting both valves Vi and Vo (accuracy);  
Step-3: Return valves Vi and Vo to the target values found in step-1. |
| **A2**   | Step-1: Achieve a steady level at any position by gradually increasing Vo in a manner that the search space for Vo is incrementally refined (stability);  
Step-2: Bring level on target by adjusting both valves Vi and Vo (accuracy);  
Step-3: Return valves Vi and Vo to target values found in step-1. |
| **B1**   | Step-1: Bring level close to target by setting valve Vi at the maximum position (accuracy);  
Step-2: Keep level relatively steady, by adjusting Vo only (stability);  
Step-3: Maintain level within limits of tolerance, by adjusting Vo in large steps (accuracy);  
Step-4: Repeat from step-2 until level is steady on its target value. |
| **B2**   | Step-1: Bring level close to target by setting valve Vi at the maximum position (accuracy);  
Step-2: Keep level relatively steady, by adjusting Vo only (stability);  
Step-3: Maintain level within limits of tolerance, by allowing it gradually to drift downwards or upwards (accuracy);  
Step-4: Repeat from step-2 until level is steady on its target value. |
| **C**    | Step-1: Bring level close to target by setting valve Vi at the maximum position (accuracy);  
Step-2: Keep level relatively steady, by adjusting both valves Vi and Vo (stability);  
Step-3: Maintain level within limits of tolerance, by adjusting Vo in large steps (accuracy);  
Step-4: Repeat from step-2 until level is steady on its target value. |
The strategies differ in the priority criterion, this being the establishment either of an accurate or a steady level, and in the sequence of control actions. The steps which are described in table 9.6, are taken to establish goal-1, once the level in the column is above the height of the exit pipeline which carries the liquid to the reboiler.

Specifically, strategy A1 sets as a priority criterion the finding of the equilibrium position of valve Vo which equates the output and input flows, and thus, makes the level steady on its way to the target position. If the level is stabilised in a position different than its target one, it should be tuned to become accurate and then steady by returning both valves to their target values. This is the most effective strategy in terms of the time taken to achieve goal-1. It has been tested on numerous instances by both the experimenter and the 'experts'. This strategy was taught to the procedures- and analysis- groups for their performance at the original task. A very similar strategy was developed for goal-3.

Strategy A2 has been developed by the 'experts' and it is basically a means-ends technique where the level is stabilised by incremental refinement of a problem space which stands for the upper-lower boundary space around the target position of Vo which is the problem at hand. For instance, if the level is rising when Vo is adjusted at the position 'x', and it is falling at the position 'y', then valve Vo is adjusted at the average position 'z' (where, \(z=x/2+y/2\)) and the level is monitored again; if the level continues to rise, the new position of Vo would be the average of 'z' and 'y' and so forth. In this way, the target position of Vo is found and the procedure continues as in strategy A1. This strategy was equally effective with the previous one, but it may not be appropriate for real plant operations since rapid changes of Vo may result in turbulent flows. For the purpose of the plant under consideration this plan remains very effective. Unfortunately, none of the trainees have come up with such a strategy.

Strategies B1 and B2 are sub-optimal, because the criterion is set upon making the level accurate regardless of the fact that it may rise or fall in the next moment. These strategies are time-consuming and may have side-effects upon a previously established goal-2. The difference between them lies in the way that the level is made accurate in step-2, either by letting it to change rapidly or gradually.
When these strategies were tried out in the plant simulator, they did not provide any clear evidence as to their relative superiority, with the speed of performance depending upon a number of factors such as number of cycles of repeating steps 2 and 3, size of adjustment of valve Vo etc. Strategies BI and B2 are the type of strategies developed by many trainees during the first few days of training.

Strategy C is ineffective and it was also employed by trainees in their first few days of training. It differs from strategies BI and B2 in that both valves are adjusted in order to achieve a steady level. It is manifested in cases where the level is stabilised on an input flow different than the target one, and thus, additional effort is required to stabilise the level again. With the increase of practice, however, trainees promote this strategy to type BI or B2.

*System prototypes and strategies for achieving goal-2*

In general, the product qualities can be established by adjusting the heating and cooling functions of the system in order to optimise the pressure in the column in response to changes of the reflux flow. To perform these manipulations effectively, the operator must have a clear understanding of the dynamics and interrelationships of various sub-systems i.e. the reboiler, condenser and column. The complex of these sub-systems constitutes the kind of system prototype the operator needs to possess in order to achieve this goal; thus, the number of alternative strategies would be expected to well exceed those available for achieving goals I and 3. However, in order to reduce the effort involved in learning such complicated prototypes, trainees were given the target value of the reflux flow which simplified the required skills to a great extent. In the context of this experiment, therefore, goal-2 could be achieved by manipulation of valves Vb and Vc only.

Although the set of alternatives in achieving goal-2 as such is small, trainees are expected to cope with difficulties arising from the instrumentation system e.g. obtaining an accurate estimate of the composition of the top product. From the analysis of the records of achievement, it appeared that three different plans had been developed to achieve goal-2, namely:
Plan-1: Gradually increase valves Vb and Vc trying to maintain level in drum at low values;

Plan-2: Gradually increase valves Vb and Vc, flushing out the level in drum whenever possible;

Plan-3: Gradually increase valves Vb and Vc until the bottom product composition is achieved; if the top product composition is still above the target, increase liquid production in the drum by increasing the positions of valves Vi, Vo, Vb, and Vc.

Plans were ranked in order of degree of efficiency, with the best one situated at the top.

Plan-2 makes the least demands in terms of learning time, and for this reason it was taught to the procedures- and analysis- groups in the original task. Some of the subjects of the analysis-group, however, converted it into plan-1 type, making some progress towards establishing goal-3 while focusing on goal-2. Finally, two subjects of the model-group developed the plan-3 type but they caused some disturbance to the composition of the bottom product, as they required additional practice to master the right size of valve adjustments. This is another example where plant-theory did not enable trainees to develop the most efficient plans.

Achieving goal-2 was a major problem for the practice-group which had no firm basis for predicting the effects of adjusting the heating and cooling functions of the system upon the product qualities. Most trainees of this group could not conceptualise the interacting relationship between these functions in affecting the pressure profile in the column and thus, the boiling points and compositions of the products. An illustration of this was the frequent overshooting of the pressure, particularly in the original task.

In summary then, goal-2 can be achieved with three different strategies within the operating conditions of this experiment. However, lack of knowledge of system prototypes caused the practice-group to spend a lot of time relieving high pressure profiles.
The role of planning elements and 'rules of thumb'

The 'one-to-many mapping' relationship found between system prototypes and plans indicates that the former do not always enable trainees to develop the most effective plan and therefore, a substantial amount of planning is required in order to achieve the three main sub-goals. Forms of planning appeared to relate to planning elements and 'rules of thumb', the latter being viewed from the perspective of capitalising upon the constrained operational conditions encountered in this study rather than developing generic rules for fitting together various subordinate tasks. Two types of planning elements which have been considered in this investigation were knowledge of goal-relationships and rules for systematic observation of the plant behaviour (see system exploration rules, in chapter 5). In this section we will consider the latter type only which gave rise to many incorrect plans in the practice-group, whereas the former type will be elaborated further in the next chapter.

In order to develop effective plans through interaction with a slow response system, trainees should be systematic in making observations about which effects relate to which manipulations. The practice-group, clearly lacked such planning elements and wrongly associated the quality of the top product (Xd) with a high degree of process overcooling or subcooling without any consideration of intervening events such as level in drum falling due to increasing Vd and thus, affecting the value of Xd displayed in the respective recorder. This gave rise to the following two erroneous plans which prevailed in the performance of the original and transfer task, namely:

- plan-1: 'In order to achieve Xd, increase valve Vc to high values';
- plan-2: 'In order to achieve Xd, decrease valve Vc to low values'.

The first plan yielded a high amount of energy consumption, whereas the latter had the disastrous effect of overshooting the pressure in the column.

Rules of thumb have been distinguished from planning elements, in that the former may enable trainees to achieve a good performance but do not necessarily result in robust and transferable plans. Such rules of thumb were extensively used by the model- and practice- groups in order to achieve the three sub-goals.
The analysis of records of achievement identified the following rules of thumb for achieving goal-1 at the original task:

Rule-1: 'Start valve Vo from a position equal to Vi';
Rule-2: 'Start valve Vo from the average position 50';
Rule-3: 'Start valve Vo from the average position 50 (+5)'.

Most of these rules of thumb which can also be applied to goal-3, can be seen as a kind of 'means-ends' analysis by which the problem space of the target value of Vo or Vd is originally reduced to the upper or lower region of the 0-100 interval of adjustment. Two trainees of the analysis-group have developed another rule of thumb which led them to modify their plans for achieving goal-3; both trainees based their estimates of the target value of Vd on the target flow of the top flow which was given to them in the specification of the transfer task, instead of applying plan-6 (figure 9.1) which they employed in the original task; thus, capitalising upon the constraints of the experiment, they managed to achieve goal-3 faster than the rest of the subjects of the same group.

Another example of rules of thumb for achieving goal-2 in the transfer task came from the performance of a subject of the practice-group who used the specified flow of the bottom product as a cue in order to find the target position of Vb, once the level in column was stabilised. This 'rule' has obviously modified the type of plan used by this subject to achieve goal-2 in the original task and resulted in a better performance. Both 'rules of thumb' and planning elements were important factors in adapting previous plans to new situations. However, the development of rules of thumb have yielded better performance but not necessarily effective plans in their own right.

The role of system complexity

As it has been mentioned previously, the transfer task was simplified in order to make the task manageable within the limited resources of the current research. To this extent, the target value of the reflux flow was specified to the subjects and the capacity of the pumps of the flow of the cooling and heating agents were kept at the same values as in the original task. As a result, goal-2 was greatly simplified in the transfer task comparing to real life situations which constitutes the most difficult part of the distillation process.
As it was expected then, most subjects of the procedures- and analysis- groups did not have any difficulty in transferring their plans for achieving goal-2 in particular. However, this was not the case for the practice-group for which most of the performance difficulties stemmed from this goal. As a generalisation then, the size of transfer observed in this study was affected by the complexity of the system under consideration. It is conceivable that a more complex system would not enable the degree of transfer observed as this would minimise the amount of common task elements between the two tasks. It is worth noting that the degree of system complexity may conceal some of the transferability aspects of different types of plans. However, this is rather a limitation of most experimental studies which are carried out with limited resources. Clearly, more research is needed to investigate the role of system complexity upon the transfer of common elements.

CONCLUSION

In summary then, this chapter has demonstrated how an integrated approach of records of control actions, observation, verbal protocols and interviews could be used to analyse behaviour at process control tasks which was multi-tasking, flexible and on some occasions erroneous. It was in this context of skill flexibility that the amount of transfer of each of the three sub-goals will be considered; as the plans used to achieve these sub-goals were ranked from effective through to sub-optimal to ineffective ones, it was possible to quantify the transfer of the three sub-goals in the next chapter.

Apart from understanding the limitations of such an investigation into human behaviour, this exercise has generated useful data for the re-assessment of the plan taxonomy so that further formalisations could make plan categories more operational than their present form. Another important aspect of this chapter was the identification of three factors - that is, mapping relationships between system prototypes and plans, the role of planning elements and 'rules of thumb', and the role of system complexity - which can account for the transfer of task elements observed. In the next chapter, we will compare the observed group differences along a number of fine-grained measures in order to take a complete view of the effects of the type of instruction upon the transfer of task elements as well as nonspecific transfer.
CHAPTER 10

ANALYSIS OF TRANSFER OF SUB-GOALS, PLANS AND NONSPECIFIC TRANSFER

SUMMARY

In order to quantify transfer of the three sub-goals and higher level plans, the individual records of achievement of all subjects in all trials were analysed with the approach described in the previous chapter. Based upon this information, the plan taxonomy was re-evaluated and further formalisations were generated in order to make the plan categories more operational than their existing form.

Another aim of this chapter was to examine two forms of nonspecific transfer, namely, development of planning elements and system prototypes separate from their contribution to the transfer of task elements. Knowledge of goal-interactions and system exploration rules were the two forms of planning elements which were considered, while knowledge of system prototypes was assessed through the questionnaire in the end of the training course.

Finally, the role of individual differences in developing training methods to optimise transfer was examined making reference to a previously derived number of fine-grained measures of behaviour such as 'efficiency' of plans, amount of 'disturbances' caused to previously established goals, number of errors and misconceptions observed and so forth.

TRANSFER OF SUBORDINATE GOALS

In the previous chapter, a number of alternative plans were identified in the performance of the following intermediate goals: 'adjust level-I in the column', 'establish product qualities' and 'adjust level-II in the drum'; as these plans were associated to different levels of efficiency, transfer of these goals to the final stage of distillation has been quantified, and it will be the focus of this
section. A binary classification of plans as either efficient or inefficient was employed, as the boundaries between sub-optimal and inefficient plans were not clear-cut. For instance, strategies A1 and A2 (table 9.6 in chapter 9) were ranked as being efficient for achieving goals 1 and 3, whilst strategies B1, B2, and C as being inefficient.

Performance of the three subordinate goals at the transfer tasks was measured along two dimensions, namely, degree of transfer (i.e. negative or positive transfer) and degree of learning or efficiency. The reference level for the former dimension is the performance of the same group at the same goal of the original task, while for the latter dimension is the standard of performance of an expert at the transfer task. This distinction is felt to be necessary in order to highlight the fact that training methods which facilitate transfer of skills do not necessarily facilitate mastery or good learning at the transfer situation. Certain training methods did not enable some trainees to learn the original task to the extent that efficient plans would be developed for the three sub-goals (e.g. model- and practice- groups); however, since those trainees managed to transfer these plans as such to the new situation, this was taken as a case of positive transfer but of low degree of learning; negative transfer referred to situations where efficient plans learned in the original task were modified and became inefficient for the transfer task. Figure 10.1 shows the number of subjects (n=7 in total) who transferred positively in trials 3 and 4, while figure 10.2 shows the portion of those subjects whose plans for the three sub-goals were considered to be efficient in the context of both the original and transfer tasks. For instance, from the six subjects of the model-group who performed goal-1 in trial-3 (figure 10.1) at least as efficiently as in the original task (an instance of positive transfer), only two of them managed to learn it to the standard of 'excellence' achieved by the subjects of the analysis-group (figure 10.2). It may be seen then, that this training method - although, it has supported transfer - it did not facilitate learning of plans to the desired standard.

Transfer of goal-1

From figure 10.1, it can be seen that all subjects of the analysis-group transferred positively their plans for achieving goal-1 in both trials 3 and 4. From the procedures-group, only three subjects transferred positively in trial 3, in comparison to six and four subjects of the model- and practice- groups
Figure 10.1. Degree of transfer of the three intermediate goals.
Figure 10.2. Degree of learning the three intermediate goals of the transfer tasks.
respectively; however, as it can be seen from figure 10.2, only two out of the six subjects of the model-group developed efficient plans compared to three out of the four subjects of the practice-group. It may appear then, that knowledge of 'how-the-system-works' did not enable all subjects of the model-group to develop efficient plans for achieving goal-1, although this group was superior to the procedures-group in the performance of the transfer task. Therefore, this type of knowledge can meet the criterion of transfer fairly well, however, it is not satisfactory when the criterion is set upon rapid acquisition of skill.

On successive practice with the transfer task in trial-4, all groups improved their performance, with the practice-group scoring high in both positive transfer and efficiency. An interesting finding of the records of achievement was that two subjects of the practice-group who were the worst in the performance of goal-1 in trial-3, together with one subject of the procedures-group managed to develop very efficient plans in trial-4. One reason which can partially explain it, could be that when trainees experience many unstable states of a system, they may appreciate those factors which may jeopardise the system and thus, perform effectively on later occasions. The difference between the procedures-and practice- groups in trial-4 (figures 10.1 and 10.2) may suggest that training methods should allow experience with transient plant states, if trainees are to appreciate the efficiency of the procedures they have been taught.

Transfer of goal-2

From figures 10.1 and 10.2, it may be seen that the procedures- and analysis-groups have scored high in both dimensions of positive transfer and efficiency in the performance of goal-2. This raises the issue of 'differential goal transfer' as the procedures-group has encountered many difficulties in performing goal-1 in a new context, but none for goal-2. A plausible psychological mechanism which can account for it, can be the mapping relationships between system-prototypes and plans. It will be recalled from the previous chapter that, goal-2 did not entail a lot of plan flexibility after its system prototype had greatly been simplified in comparison to goal-1 which could be achieved in at least five different ways. If we construe this mapping relationship as a measure of task difficulty, then goal-1 would appear to be more difficult than goal-2 as entailing a great performance flexibility; in
addition, performance at goal-1 may be the greatest contributor to the overall performance as the symptom propagation is mainly downstream under the operating conditions encountered in this study.

Performance of the practice-group at goal-2 of the transfer tasks has highlighted the role of system exploration rules and conceptual knowledge of the system; five subjects of this group developed erroneous rules in their efforts to achieve the top product composition at the original task. However two of those trainees improved their plans in trial-4, and had a better performance of goal-2. On the contrary, one subject of the model-group who performed goal-2 effectively in the original task developed erroneous rules on transfer to the new context, and this was the only case of negative transfer at goal-2 in the transfer task.

Transfer of goal-3

Goal-3 entails the same performance flexibility as goal-1, however, its contribution to the overall performance is much smaller than the one of goal-1. This can explain in part the fact that trainees did not pay much attention in performing goal-3 in a consistent manner over the original and transfer tasks. With the exception of the analysis-group, all the other groups did not develop efficient plans for carrying out goal-3 (figure 10.2). Part of the success of this group could be attributed to the development of a plan for integrating goals 2 and 3 without the need to carry out the intermediate task step of flushing out the level in the drum at regular time intervals.

TRANSFER OF DIFFERENT TYPES OF PLANS

So far we have considered the transfer of intermediate goals and the role of mapping-relationships and planning elements in the size of transfer observed. However, each of these goals is an organisation of lower-level goals and plans which entails consideration of the transferability of these constituent plans. In this section, we shall consider transfer of lower-level plans as well as high-level plans which sequence the three intermediate goals. We shall scan the different plans in a top-down fashion as these were displayed in the HTA of the transfer task (see figure 9.1 in chapter 9).
Plan-B

The top plan-B was trained as a fixed sequence (FS) type to the procedures- and analysis-groups. However, as it can be seen from figure 10.3, many trainees have carried it out as a fixed cycle (FC) type, especially with successive practice on the transfer task in trial-4; this tendency was greater for the analysis-group. The model- and practice-groups performed this plan either as a FS or FC type right from the original task, with an emphasis on FC type in the performance of the transfer task. Indeed, a FC type can be a more efficient plan for the transfer task, provided that trainees get to know when to switch attention to operations 5 and 6 (see figure 9.1). However, trainees of the practice-group who did a FC plan in the original task, had many difficulties in achieving the quality of the top product and they developed many erroneous-rules.

Carrying out plan-B as a FC type on the part of the analysis-group, can be seen as the contribution of planning elements in 'fitting' together subordinate operations; trainees of this group modified operations 6 and 5.2.2 and instead of 'flushing out level-11 in the drum', they attempted to stabilise it at low values in order to get an estimate for both the target value of valve Vd and the composition of the top product. A FC type plan can be even more effective, when operation-6 is attended after the quality of the bottom product has been achieved and the quality of the top product is on its way to the target, although this cannot be confirmed from the respective recorder. When such planning elements are developed, the number of cycles entailed in a FC plan is kept to a minimum. In fact, this has caused some confusion in distinguishing plan-B as being of FS or FC type, since performance of operation-6 started quite late, after some progress had been made towards operation-5; however, as subjects altered between these operations, this plan assigned to FC type.

A new feature of the FC type then, is the number of cycles involved, with more competent subjects having some knowledge of the cases when to switch attention over to each subordinate operation, keeping the number of cycles to an optimal value.
Figure 10.3. Types of the overall plan-B adopted by trainees.
Plan-5

The intermediate level plan-5 was trained as a fixed sequence (FS) type to the procedures- and analysis- groups. Figure 10.4 shows that other groups have carried it out as either a fixed sequence (FS) type or fixed cycle (FC) or time-sharing (TS) type. Even three subjects of the analysis-group performed this plan as a FC type, straight from the original task (trial-2). An interesting finding was that the majority of the subjects did a FC type on transfer to the new task (trials 3 and 4), with most trainees of the model-group performing it as a TS type.

Clearly, a TS type is the most efficient plan for the transfer task, provided that trainees have mastered the right size of adjustments of valves Vo and Vb; unfortunately, this was not the case for all trainees of the model-group (see record of subject S5 in chapter 9), and as a result they did not achieve a better control performance than the analysis-group which utilised a FC type (see figures 8.4 and 8.5 in chapter 8). A FC type can be an effective plan when trainees adjust valve Vo in small steps in order to avoid side-effects on goal-2 (see record of subject S4 in chapter 9). A FS type is a sub-optimal plan for the transfer task, and this has been recognised by most trainees (see figure 10.4).

On many occasions, trainees were inconsistent and performed plan-5 as a FC type, and where the opportunities arose they switched to a TS type; when this was the case, plan-5 was assigned to the plan category with the greatest frequency of occurrence.

Plan-4

This plan was carried out as a remedial cycle, and it did not present any difficulties to the trainees, since the target value of the reflux flow had been specified to them.

Plans 5.1 and 6.

A fixed sequence type was specified for these plans to the analysis- and procedures- group. Although most trainees carried out these plans as FS types, transferability of this plan was influenced by considerations of priority.
Figure 10.4. Types of the intermediate plan-5 adopted by trainees.
criteria, these being either the stability or accuracy of the level. For a more elaborate discussion see previous section of transfer of goals 1 and 3.

Plan-5.2

This plan was specified as an integrating plan (IP type) to the analysis- and procedures- groups. However, as this plan played an auxiliary role in achieving the main operation-5.2.1, it was abandoned by most trainees of the analysis-group or modified to a fixed cycle plan with the development of planning elements e.g. 'flushing out level-II’ was initiated once the composition of the bottom product approximated its target value. This plan proved to be very efficient in the performance of these groups on the original task, since it assisted trainees to avoid development of erroneous-rules or ineffective plans associated with the task of achieving the top product quality.

Plan-5.2.1

Most subjects of the analysis- and procedures- groups transferred this time-sharing plan positively to the new task, as they realised that in order to achieve the product qualities, the pressure profile should always be optimised, in conjunction with the increase of evaporation. However, a few subjects of the practice-group performed this plan as a FC type, and as a result they increased the pressure to high values since they could not correctly judge when to switch attention to the subordinate operations.

Plans 5.2.1.1 and 5.2.1.2

Plan-5.2.1.1 was a remedial cycle plan and it was positively transferred to the new context. However, the decision plan-5.2.1.2 was converted to a FS type plan, since trainees learned with the increase of the expertise that operation-5.2.1.2 should be mainly carried out by adjusting valve Vc only in order to minimise any disturbance to already established compositions of the bottom product.
NONSPECIFIC TRANSFER

Although the current experiment has been designed in such a way that the primary support of performance in the transfer task should be due to the three intermediate goals mastered in the context of the original task, the individual differences observed and the modification of plans may suggest that a small portion of the group differences can also be explained by a 'nonspecific transfer' argument. An examination of two forms of nonspecific transfer—namely, development of planning elements and system prototypes—was carried out using a number of indirect measures such as frequency at which goal-2 was disturbed by previous manipulations of goal-1 and a questionnaire in the end of trial-4. The results displayed in this section show that some groups had a better knowledge of planning elements and system prototypes, however, it is difficult to examine in any degree of precision the extent that these types of knowledge had any substantial contribution to the overall performance, since the two tasks had many elements in common.

Development of planning elements

Two forms of planning elements which have already been mentioned are 'knowledge of goal-interactions' which enables trainees to sequence the three intermediate goals in an effective manner, and development of 'system exploration rules' which can assist trainees to construct responses by systematic observation of the way the system responds to previous manipulations. As knowledge of goal-interactions manifests itself in the way trainees 'fit' together various intermediate goals, the primary measure to be used is the frequency at which goals 1 and 2 are successfully integrated (see Planning Elements Score in chapter 7). The experimental hypothesis was that 'in both transfer tasks, the analysis- and model- groups would achieve a higher PES than the procedures-group which would be better than the practice-group in this respect'. Figure 10.5 displays the observed group differences in the performance of both transfer tasks in terms of the Planning Elements Score.

A two-way repeated measures ANOVA showed significant method-effects (F=4.38; df=3,24; p<0.02), no significant interaction (F=0.52; df=3,24; p=N.S.), and no improvement on the successive transfer task on trial-4 (F=0.14; df=1,24; p=N.S.). A two-tailed t-test upon the main method effects showed that the
Figure 10.5. Planning Elements Scores.
procedures-group performed significantly worse than both the analysis-group (t=3.02; df=24; p<0.01) and the model-group (t=3.19; df=24; p<0.01).

The practice-group, which had a lower score than the analysis- and model-groups in trial-3 (yet not significantly lower), managed to approach these groups in trial-4 and performed better than the procedures-group in both trials (yet not significantly better).

The difference between the procedures- and the practice- groups was an interesting finding which has not been anticipated in the experimental hypothesis. Again, the argument of high 'exposure' to transient system states may account for the fact that the practice-group did not disturb goal-2 as frequently as the procedures-group did; this does not, however, mean that the practice-group had learned how to time-share goals 1 and 2. From the records of achievement, it appeared that the practice-group was very conservative in adjusting goal-1 (that is, Vo was adjusted in small steps), as it was aware of any side-effects to goal-2, yet not being able to cope with them. An additional factor associated with this finding is that most subjects of the practice-group set as a primary criterion for establishing goal-1 the stability rather than the accuracy of the level, which had clearly an effect upon their PES. Therefore, the experimental hypothesis was partially confirmed only.

The measure of control performance of the bottom product is clearly associated to the PES measure; however, this relationship is not linear because a number of other factors apart from the number that goal-2 was disturbed intervene i.e. size and duration of disturbances. This consideration can explain why the model-group which achieved a higher PES than the analysis-group (trial-4, figure 10.5) had an inferior control performance (see figures 8.4 and 8.5).

The other form of planning elements is the development of system exploration rules. Lack of this form of planning elements on the part of the practice-group led many trainees to develop incorrect plans in order to achieve the quality of the top product. It seems then, that some form of 'guided discovery' might be more appropriate for this group, if they were to successfully explore their experience with a dynamic and interactive learning environment.

From the analysis of the records of achievement it appeared that the analysis-group was very concerned with any side-effects on the quality of the bottom
product and it established goal-1 by making gradual and small-step adjustments of valve Vo (steps were less than five units). As a result, the number of goal-1 adjustments, for this group, was half of the ones performed by the other groups. This finding, in conjunction with the fact that only one subject of the analysis-group time-shared goals 1 and 2 compared to four subjects of the model-group, may suggest that the analysis-group had a more conservative criterion than the model-group. It is plausible that the analysis-group had judged that their experience with the transfer task would not enable them to estimate the right size of adjusting valves Vo and Vb and that a time-sharing plan might be premature at this stage of practice. Indeed, the model-group which adopted such a type of plan had a worse control performance since the theory of the plant did not enable them to get a 'feel' for the size of valve adjustments. These differences were suggested, based upon information given by the subjects in their interview in the end of the experiment, since these could not be captured by the PES measure.

On some occasions, however, it was difficult to separate the effects of planning elements and system prototypes, as in the example of the two subjects of the procedures- and practice- groups in trial-4 who stabilised the level in the column against a feedflow different than the target one; this is an illustration of the lack of either types of knowledge. Another example is the inability of all subjects to describe the state of the plant when the reflux flow was increased, a symptom appeared in both trials 3 and 4; this again illustrates both lack of conceptual knowledge and systematic observation of important plant states.

Development of system prototypes

Conceptual knowledge about the functioning of the system was measured in terms of the Correct Answer Score (CAS) of the questionnaire. From the total ten questions, six of them concerned compensatory actions, whilst the remaining four concerned diagnosis of abnormal situations. The experimental hypothesis was that 'the model- and the analysis- groups would achieve a higher CAS than the procedures-groups, which would be better than the practice-group in this respect'. Figure 10.6 shows the different scores achieved by the four groups in answering the questionnaire.
Key:
- : Procedures-group;  : Analysis-group;  : Model-group;  : Practice-group;

Figure 10.6. Questionnaire scores.
A one-way analysis of variance found significant differences between method effects \( (F=14.19; \, df=3,24; \, p<0.001) \), when all of the ten questions were considered. A two-tailed \( t \)-test upon the method effects showed that the procedures- and practice- groups performed worse than both the model- group \( (t=5.41; \, df=24; \, p<0.001) \) and the analysis-group \( (t=2.98; \, df=24; \, p<0.01) \). However, the hypothesis was only partially confirmed since the procedures- and practice- groups achieved comparable scores, whilst the model-group performed significantly better than the analysis-group \( (t=2.42; \, df=24; \, p<0.05) \).

To clarify the source of the latter difference, two separate one-way analysis of variance were carried out on the mean scores of the six first questions (compensatory questions) as well as the remaining four (diagnostic questions).

The groups differed significantly in their scores on the compensatory questions \( (F=9.55; \, df=3,24; \, p<0.001) \) with the procedures- and practice- groups having achieved significantly lower scores than both the model-group \( (two-tailed \, t\text{-test}, \, t=4.32; \, df=24; \, p<0.001) \) and the analysis-group \( (two-tailed \, t\text{-test}, \, t=3.107; \, df=24; \, p<0.01) \). However the difference between the model- and the analysis- groups was not significant, and neither was the difference between the other two groups. With respect to the diagnostic questions, the group differences were also significant \( (F=9.04; \, df=3,24; \, P<0.001) \), with the model-group having achieved the highest score of the other groups. A two-tailed \( t \)-test found this difference to be significant with the procedures-group \( (t=4.66; \, df=24; \, p<0.001) \), with the practice-group \( (t=4.27; \, df=24; \, p<0.001) \), and with the analysis-group \( (t=3.5; \, df=24; \, p<0.01) \).

In conclusion then, it appeared that the overall difference between the model- and analysis- groups was mainly due to the diagnostic questions rather than compensatory ones. It is conceivable that the planning knowledge which was taught to the analysis-group was specific to the compensatory activities only, and it did not cover aspects of the diagnostic phase. Conceptual knowledge, on the other hand, appeared to have offered the model-group a better assistance in the diagnosis of abnormal events. Finally, no difference was found between the procedures- and practice- groups which was not expected in the hypothesis. It is plausible that the practice-group acquired a good understanding of the functioning of the system since trainees had to cope with many transient states in the learning of the original task.
DISCUSSION

In this section, an overview will be given of the effects of the training methods upon the acquisition and transfer of skills. In addition, the proposed plan taxonomy will be elaborated in view of the findings of the transferability of plans between and within categories. Finally, the role of the individual differences in the design of training will be discussed further.

The effect of training methods upon the acquisition and transfer of skills

In the past, many studies have argued for the superiority of certain instructional methods in the performance of process control skills. The contribution of this research concerns the major finding that the effectiveness of a particular training method should refer to two different criteria, namely, acquisition versus transfer of skill. In chapter 8, it has been found that the procedures-group, which was superior to the model-group in the original task, became inferior in the transfer task. The analysis-group, on the other hand, performed efficiently in both tasks, since the planning knowledge was deliberately designed to overcome the weaknesses of the other methods.

This distinction between acquisition and transfer of skills was best illustrated in the performance of goals 1 and 3 by the model- and procedures-groups. Specifically, the model-group achieved a high transfer score (figure 10.1), however these goals were not mastered to the desired standard (figure 10.2); on the other hand, the procedures-group had a low transfer score since these goals were not performed as effectively as in the context of the original task (see low degree of efficiency in figure 10.2). It may be concluded, therefore, that 'plant-theory' did not enable trainees to develop more efficient plans than the ones specified in the 'procedures'; however, it did facilitate transfer and improvement of plans to a greater extent than the 'procedures' condition. Since the difficulty of the task has affected performance, the former two groups achieved comparable performance at goal-2. Therefore, 'plant-theory' may be seen to support recognition of 'common elements' and facilitate transfer, particularly with the increase of task difficulty; however, it does not guarantee efficient performance of the original task.

On the other hand, the practice-group developed efficient plans for achieving goals 1 and 3 in the transfer situation which were comparable to the ones
developed by the procedures- and model- groups. An interesting result, however, was that the practice-group had better plans for goal-1 in trial-4 than the other two groups, but it did not perform better since the plans for goal-2 were proven to be erroneous (see figure 10.2). This can partially be attributed to the fact that the practice-group had developed some form of planning knowledge (see figure 10.5) which supported performance of goals 1 and 3, however, they had not developed a good conceptual knowledge (see figure 10.6) and their performance of goal-2 was poor. This is another important finding of the current research, namely, that experience with a plant-simulator may benefit only those tasks which require planning knowledge, whereas those requiring conceptual knowledge may be performed sub-optimally. It seems then, that trainees may not be able to develop a complete 'mental model' of 'how-the-system- works' solely on the basis of practice, and that some form of 'guided discovery' is necessary to support understanding of the system through experience.

The analysis-group appeared to have the highest score of transferability and efficiency for all three sub-goals, however, it did not perform better than the model-group as far as nonspecific transfer was concerned. The present experiment was designed to control for nonspecific transfer effects, however, the differential transfer of goals and the individual differences within groups indicated that such effects had actually taken place. The scores for the development of planning and conceptual knowledge were indirect, thus, they were not expected to reveal the complexity of nonspecific transfer. From figures 10.5 and 10.6, it may be concluded that the model-group achieved similar PES and questionnaire scores (compensatory questions only) to the analysis-group. To this extent the experimental hypotheses about nonspecific transfer were confirmed, however, the model-group answered more diagnostic questions than the analysis-group, and as a result, its overall performance was better (see figure 10.6). It may appear then, that the type of planning knowledge required to control the plant effectively does not necessarily enable trainees to diagnose failures. It is conceivable that other aspects of planning elements should also be emphasised e.g. those advocated by Shepherd et al. (1976).

The task described in this experiment consisted mostly of compensatory activities taken during the start-up of the plant. Although, diagnostic skills are closely related to start-up operations, they may play a minor role to the task in cases where operators have acquired adequate knowledge how to plan
their activities so that the likelihoods of errors are minimised. This might have been the case for the analysis-group which avoided many errors and thus, its members were not required to diagnose any sources of abnormal situations. Clearly more research is needed to establish the role of planning and conceptual knowledge in process control tasks with a substantial diagnostic component.

Elaboration of the plan taxonomy

The proposed plan taxonomy will be evaluated in this section, in view of the findings of the experimental study. A major implication for the transferability of plans is that the different plan categories have not clear-cut divisions, as expertise seems to develop through a smooth shift along many plan categories until it resides with the most appropriate ones. It is conceivable that where a great deal of performance flexibility exists in a skill, trainees would try out different types of plans, all of them being equally effective in the initial stage of learning. With the progress of learning, however, certain types of plans will be preferred. Three major factors are likely to affect the process of plan transformation which, in turn, are affected by the stage of learning and type of instruction received, namely: conceptual knowledge, planning knowledge, and opportunistic performance (e.g. rules of thumb). Understanding the precise psychological mechanisms of these transformations would be beyond the scope of this study, however, we would explore the utility of these observations in the prediction of between-category transfer of plans.

Another finding was the distinction between plan effectiveness and plan transferability. It is worth noting that effectiveness would considerably be affected by factors other than plan-category such as response criterion, size of valve adjustments etc. An example would be the performance of plan-5 (see figure 10.4); when small adjustments of valves are sequenced through a fixed cycle plan, performance may be superior to a time-sharing plan in the initial stage of learning where trainees cannot coordinate valve adjustments. On the other hand, transfer of plans within the same category will be affected by the trainee recognising the required amount of modification without the need to change the priority criterion. A good example would be the case of the procedures-group which sub-optimally transferred their plans for goals 1 and 3.
In order to describe the observed transformations of plan categories in a more concise manner, the existing plan categories were assigned to the following four groups:

(i) *Sequential plans* which include fixed-, contingent- and optional- sequences;
(ii) *Cycle plans*, which include fixed- and remedial- cycle plans;
(iii) *Concurrent plans*, which include time-sharing and integrating- plans; and,
(iv) *Decision plans*.

Discretionary plans can be another group of plans, however, these will not be included here due to the lack of data. Each group will be considered below in a greater detail.

**Transfer of sequential plans**

It will be recalled from chapter 3, that an optional sequence plan can be transformed into a fixed- or contingent-type, when experience enable operators to derive the most effective sequence. When sequential plans govern a limited number of subordinate operations, they can be transformed into a fixed cycle type (e.g. plans B and 5) or even an integrating or time-sharing one (e.g. plan-5). These transformations can be the result of expertise as trainees better understand the particularities of a system and the various goal-interactions.

**Transfer of cycle plans**

Remedial cycle plans are unit plans which are very common in process control and operate in the same way that an automatic controller does. Fixed cycle plans, on the other hand, sequence more than one operations and they are the usual type of plan which trainees resort in the initial stage of learning of a time-sharing plan. As a result, the transformation of a fixed cycle to a time-sharing type is a common phenomenon where a goal-interaction exists e.g. plans 5 and 5.2.1, (see also Shepherd, 1989).
Transfer of concurrent plans

Integrating plans can be converted to fixed cycle types, particularly with the development of planning elements and rules of thumb (e.g. plan-5.2). On the other hand, time-sharing plans tend not to transform into other types, once the 'timing' and 'size of adjustments' have been mastered; these plans require a lot of practice and trainees will eventually master them by acquiring a series of other plan types throughout the learning process.

Transfer of decision plans

Decision plans can usually be redescribed into a hierarchy of simpler plans; the best example is probably the conduct of a HTA by the analyst. In general, it is quite difficult to record the criteria employed by trainees in choosing certain kinds of decision-plan decompositions because most part of this knowledge is tacit. Post-event interviews may not elicit the precise criteria employed during plant operation and thus, offer a limited amount of assistance to the analyst.

In the present study, a large amount of between-category transfer of plans was observed due to the flexible nature of the represented task. The conclusions of this section are rather tentative since only certain aspects of the performance of the task were controlled. This is a common feature of experiments using industrial tasks as opposed to laboratory tasks. Clearly, had the present study focused on a laboratory task, better control could be exerted on the task.

The role of individual differences in training design

In order to examine individual differences observed within the same group, a number of fine-grained measures of performance were employed regarding transfer of sub-goals and high-level plans. In general, the conclusions of this section is in congruence with the ones reached in chapter 8.

Specifically, individual differences in the performance of transfer of the three sub-goals can be examined by considering the number of subjects who
performed effectively the three sub-goals; the dimension of transferability will not be considered, because it also includes transfer of suboptimal plans. In the performance of goals 1 and 3, most trainees of the analysis-group performed equally well, however, efficiency of the other groups may be attributed to some individuals achieving higher scores than others within the same group. On successive practice with the transfer task, however, most trainees of the practice-group performed goal-1 effectively. Performance of goal-2 showed very small individual differences, possibly with the exception of the practice-group whose trainees developed erroneous 'rules'. It may be concluded then, that individual differences may be aggravated with the increase of task difficulty, since less trainees would be able to make effective use of their instructions. Nevertheless, an effective training method would enable even the 'slow' learners to catch up with the 'faster' ones; this appeared to be the case in the training of the analysis-group.

Performance of the overall plan-B (figure 10.3) shows that most trainees of the analysis- and procedures- groups adopted the same type of plan in the performance of the original task, in contrast to the other two groups which showed large variability. In the performance of the transfer task, however, this trend disappeared with all groups showing large variability (possibly, with the exception of the analysis-group). On the other hand, performance of the intermediate-level plan-5 showed a different pattern. Specifically, the model- and procedures- groups showed smaller variability than the other groups in the performance of the original task; however, on transfer to the new situation, the analysis- and procedures- groups showed less variability than the other groups.

The generalisation made in chapter 8, namely that 'the more effective training method may enable the less competent trainees to reach the performance of the more competent trainees of a less effective method' appears to be valid in the context of the findings of this chapter. In the design of training, it is worth pointing out that, some trainees will extract the maximum benefit from an instructional method, whilst other will encounter difficulties. It is conceivable that the 'slow' learners would require additional practice in order to reach the performance of the 'able' ones.
CONCLUSION

This chapter has attempted to quantify transfer of sub-goals and higher level plans based upon information on a number of fine-grained measures derived from the analysis of the individual records of achievement. The results are in congruence with the overall performances examined in chapter 8, and they have indicated that training methods which facilitate rapid acquisition of skills do not necessarily support transfer. The only exception to this rule was the performance of the analysis-group which received a particular type of knowledge to overcome these problems. The plant-theory appeared to support transfer of skills, however it did not enable full mastery of goals 1 and 3 in the context of both the original and transfer tasks. On the other hand, the teaching of 'procedures' did not enable all of the subjects to transfer their skills. Furthermore, the practice-group appeared to perform goal-1 better than the procedures-group in trial-4, pointing out the role of 'active' learning in the original task; it was obvious that the former group had experienced more transient process states than the latter and developed more efficient plans. This may imply that some sort of extrinsic training information may be required in addition to the 'procedures' in order to support transfer of skills which entail a high degree of flexibility.

An important cognitive mechanism has been identified as influencing the transfer of skills; specifically, the mapping relationships between system prototypes and plans could account for the fact that most trainees achieved a higher transfer score in goal-2, but not in goal-1 which entailed a greater flexibility in performance. Another influencing factor was the contribution of a particular goal to the overall task performance; performance of goal-3, for instance, had a low contribution to the overall performance and as a result, trainees appeared to be inconsistent over the original and transfer tasks.

The individual differences observed and the modifications in plans have indicated that some degree of nonspecific transfer had occurred. Both experimental hypotheses about transfer of planning elements and development of system prototypes were supported to a certain extent. A finding which was not expected was that the performance of the practice-group was equivalent to the procedures-group as far as nonspecific transfer was concerned. The previous argument of 'active' learning through practice with an interactive simulator may account for this finding as well. With respect to the development of system prototypes, the model-group appeared to have answered
more questions than the analysis-group, however, this was the result of the questionnaire having included a number of diagnostic questions in addition to the ones referring to compensatory actions.

In order to make some generalisations with respect to the between-category transfer of plans, four broader categories were suggested, namely, sequential plans, cycle plans, concurrent plans, and decision plans. Further research is needed in order to investigate this type of transfer in a more systematic way.

Finally, the role of individual differences in learning deserves further research, and it should always be taken into account in the design of training.
OVERVIEW OF FINDINGS AND CONCLUDING DISCUSSION

SUMMARY

The experimental findings are discussed in the context of the five hypotheses concerning the acquisition and transfer of task elements as well as nonspecific transfer. In general, training methods which enabled rapid acquisition of skills did not necessarily support transfer, with the exception of the type of instruction provided to the analysis-group. The role of planning and conceptual knowledge in the transfer of skills is subsequently discussed.

The proposed HTA appeared to be a valuable tool in describing task elements in formally similar forms which is the initial stage in setting appropriate learning conditions to optimise transfer. A decision aid in achieving this end has also been suggested; however, the issue of within- and between- category transfer of plans deserves further research as such.

The problem of making recommendations for training design in a systems context is then discussed in the context of an 'adaptive training simulator' based upon the proposed model of response learning. Finally, the approach of this thesis to the transfer of skills is evaluated and directions for future research are proposed.

MAIN AIMS OF RESEARCH

Process control tasks are complex cognitive tasks since a whole repertoire of skills need to be mastered. Questions then arise as to how training would enable trainees to integrate the composite elements into the overall skill by taking advantage of similar behaviours entailed in various elements as well as coping with contradictory ones. This issue of 'internal-task' transfer was precisely the focus of the present research which has sought to examine the
学习条件，在这些条件下，这种转移机制会支持整体技能的获得。

研究行为模型和培训问题的进展是以‘杂乱无章’的方式进行的；从提出每个任务元素的不同的知识和技能，以及操作员在没有帮助的情况下整合这些技能。另一方面，实验性的转移研究主要考察的是相对简单的感知-运动任务和文本编辑技能，因此他们的发现对于过程控制的适用性有限。有人认为“运行一个工厂”的技能不仅在于掌握各种界面操作（刺激-反应单元）和理解基本操作原理，而主要是在于计划如何选择和顺序这些在适当顺序。因此，有理由考察比以前转移研究中所研究的更大的单位的性能。

为了考察规划行为的方面在过程控制中的转移，采用了一种任务描述方法（层次任务分析），按照该方法任务被重新描述为计划和操作的层次。通过定义相似性关系的分类方案的计划和目标，已经展示了如何将复杂的计划任务重新描述为两个阶段，每个阶段共享三个中间目标。最大限度地提高共同任务元素的数量是提出的HTA的主要贡献。

在论文中测试的一个重要研究问题是“是否有相似形式的共同任务元素会促使个体采用相似行为，从而转移会受到影响”。在粗略水平上，结果显示所有实验组都识别了最相似关系，与原始任务相比，在速度和控制性能方面显著优于控制组和练习组。到这个程度，HTA似乎是一个有用的工具，可以以这样一种方式重新描述任务，从而可以对转移的共同任务元素做出定性的预测。

然而，关于转移效应大小的定量预测是不可行的，除非有一个学习模型，这个模型会假设可能的训练方法，这些方法将使受训者从掌握原始任务中获得最大利益。该模型是“目标响应集距离”的模型。
learning has been suggested to examine conditions which optimise transfer. To this extent, the following four training methods were tested for their transfer potential:

- learning of 'procedures';
- learning of 'procedures' and additional planning knowledge;
- learning of a 'model' of the behaviour of the plant; and,
- learning by 'practice' (control condition).

A large scale experiment was designed in order to investigate the 'role of type of training method upon transfer of common task elements'. An effort was made to control for nonspecific transfer effects by means of maximising the number of common task elements as well as constraining practice of the original and transfer tasks to a few trials only. However, some degree of nonspecific transfer was expected to occur in the experiment due to the nature of process control tasks which require complex cognitive skills. Based upon the proposed learning model, two hypotheses about nonspecific transfer were addressed, namely, transfer of planning elements and system prototypes. This, however, was a peripheral issue in the current research.

In the light of the experimental findings, the proposed plan taxonomy was elaborated further with respect to its potential for making transfer predictions. Finally, the thesis has looked into the role of individual differences in the design of training.

**METHODOLOGICAL ISSUES**

To test the hypotheses put forward, the task of 'starting-up a distillation column' was represented in a microcomputer. The difficulty of the original and transfer tasks were adjusted by means of conducting a pilot study on a plant simulator prior to the main experimental study. A number of factors such as display mode, size of column, location of instruments, accuracy required, size of valve adjustments and time-base were identified as having a considerable effect upon the initial stage of learning of both tasks. In addition, size of valve adjustments and time-base were found to confound with the effectiveness of training methods since they enabled subjects to use the 'predictive' display facilities of the simulator and derive a great deal of their
Another important factor which may affect the outcome of transfer studies may be the type of transfer formulas employed. Due to the large scale and task complexity of the experiment, only a 'first-shot' transfer measure was used. However, subjects were tested on a second trial of the transfer task in order to get an estimate of the 'saving' aspects of transfer.

Performance at both tasks was measured in terms of speed, control performance and economy of operation. However, a set of fine-grained measures was also used e.g. plan 'efficiency', amount of 'disturbance' caused to already established parameters, erroneous plans and misconceptions. This was necessary in order to get an insight into the transfer of individual goals and plans as well as nonspecific transfer. To this extent, a battery of data collection techniques were used such as 'state-action' pairs, verbal protocols, observations, and finally, an informal interview and a questionnaire in the end of the experiment. This approach managed to overcome some of the 'plan recognition' problems associated with multi-tasking, flexibility and erroneous performance which have been reviewed in chapter 9.

OVERVIEW OF EXPERIMENTAL FINDINGS

In this section, an overview is presented of the experimental findings concerning the five hypotheses about specific and nonspecific transfer which were based upon the 'Goal Response Set Distance' model of learning.

Performance at the original task

The first hypothesis stated that 'all groups will perform better than the practice-group, with the analysis- and procedures- groups being superior to the model-group'. The results indicated that most groups stabilised their performance in trial-2; the practice-group performed equally well to the model-group in terms of the control and economy aspects of performance, one reason being that the model-group continued to experiment with the simulator degrading its performance from time to time. On the other hand, the
difference between the practice- and analysis- groups in terms of economy of operation failed to reach significance; it is conceivable that most of the difficulties encountered by this group concerned the performance of the time-sharing plan-5.2.1 which was not completely specified in the original situation. Finally, the procedures- and analysis- groups performed significantly better than the model-group in all aspects of performance.

**Performance at the first trial on the transfer task**

The second hypotheses stated that 'all groups will perform better than the practice-group, with the analysis-group being superior to all groups; the model-group will perform better than the procedures-group'. At the first trial on the transfer task, all groups performed better than the practice-group in terms of speed and control performance only. No differences were found in terms of economy of operation since most subjects developed appropriate 'rules of thumb', and because the transfer task required them to stay on the high energy mode for prolonged periods. The analysis- and model- groups performed better than the procedures-group; however, the difference between the latter two - although considerably high (24%) - did not reach significance for the control performance. Finally, the analysis-group was superior to the model-group in terms of speed and control performance (approx. 18%), however, this difference was not significant mainly due to individual differences.

**The effects of practice on transfer**

The third hypothesis stated that 'all groups will improve their performance on a successive transfer task, with the procedures-group reaching the performance of the model-group; all groups will perform better than the practice-group'. Group differences on trial-4 showed a pattern different than the one expected in the third experimental hypothesis. While the procedures- and practice-groups showed a significant improvement on all aspects of their performance, the analysis-group improved its control performance only, and the model-group spent less energy. The main significant differences were between the analysis- and practice- groups in terms of speed and control performance, the other groups having scored in between the two previous groups. In addition, the analysis-group performed faster than the procedures-group. Large individual
differences in the procedures- and practice- groups may be an important reason for not finding larger support for the third experimental hypothesis.

Development of planning elements

Two forms of planning elements were identified in this study, that is, 'knowledge of goal-interactions' which was measured with the Planning Elements Score (PES) and development of 'system exploration' rules which was subjectively assessed from the individual records of achievement. The fourth hypothesis stated that 'in both transfer tasks, the analysis- and model-group will achieve a higher PES than the procedures-group which will be better than the practice-group in this respect'.

The results indicated that the analysis- and model- groups achieved higher PES than the other groups, however this difference reached significance only with the procedures-group. An interesting finding which was not anticipated in the fourth hypothesis was that the practice-group achieved a higher PES than the procedures-group (yet not a significant one). High 'exposure' of the practice-group to transient system states may be one reason accounting for this difference in performance. An additional factor may concern the performance of goal-1 which had an effect upon PES, with the practice-group setting as a primary criterion the stability rather than accuracy of level-1, in contrast to the procedures-group. Consideration of the other form of planning elements provided some explanation for the misconceptions and erroneous plans adopted by the practice-group in order to achieve goal-2. It was felt that some form of 'learning by guided discovery' would enable the practice-group to develop 'system exploration' rules and perform goal-2 more effectively.

Development of system prototypes

Conceptual knowledge about the functioning of the system was measured in terms of the Correct Answer Score (CAS) in the questionnaire. The fifth hypothesis stated that 'the model- and analysis- groups will achieve a higher CAS than the procedures-group which will be better than the practice-group in this respect'. In general, the model- and analysis- groups were found to perform significantly better than the other groups. The fifth hypothesis was partially supported since the model-group performed better than the analysis-
group, while the other two groups achieved comparative scores. When the questionnaire was partitioned into diagnostic and compensatory questions, it was found that the difference between the model- and analysis-groups could be attributed to the diagnostic questions which had not been very well addressed in the training information given to the analysis-group. With respect to the observed differences between the practice- and procedures-groups, it was assumed that the previous argument of high 'exposure' to transient system states would be valid for this occasion as well.

Discussion

A major finding of this study concerns the role of instruction in the acquisition and transfer of skills. Specifically, training methods which facilitate rapid acquisition of skills do not necessarily support transferability to new contexts. While the procedures-group, for instance, was superior to the model-group in the original task, its performance became inferior in the transfer task. It was only when the 'procedures' condition was furnished with a form of planning knowledge that a large amount of transfer was observed (see performance of the analysis-group). The performance of the model-group has implication for the role of conceptual knowledge in the performance of process control skills. It appeared that constructing responses on the basis of this type of knowledge cannot guarantee that all trainees will be able to appreciate how 'plant-theory' can be put into practice with a limited amount of practice. This situation is aggravated in complex environments where a response may achieve a desired outcome, yet it may not be the most effective solution to the problem. Flexibility of performance can also account for the transfer results, where trainees will have to recognise what elements of their skills are appropriate in a new context. In this respect, the model-group performed well in the transfer task in comparison to the procedures-group whose trainees had difficulties in recognising the most efficient plans suitable in the transfer task.

This distinction between the acquisition and transfer aspects of performance was reinforced from an in-depth analysis of the transfer of the three subordinate goals. Performance at goals 1 and 3 showed that the model-group, although achieving higher transfer scores, did not develop more efficient plans than the procedures-group. It was rather the inability of some trainees of the latter group to recognise the similarity relationships between the two tasks that
resulted in this group having a lower transfer score. It may be concluded then, that conceptual knowledge is not adequate for rapid skill acquisition; however, it may support performance of even sub-optimal plans to a new context. It is conceivable that had the 'procedures' condition been furnished with additional conceptual knowledge, a higher transfer score may have been achieved. This condition was not included in the present study, however, since learning of 'plant-theory' is a much more laborious method than learning of planning knowledge.

The role of learning in an interactive environment was another issue which was highlighted by the performance of the practice-group as well as the practice effects of all groups in the transfer task of trial-4. 'Exposure' to many transient system states and immediate feedback from the plant simulator enabled the practice-group to achieve a relatively good transfer score particularly in trial-4. Problems, however, were encountered in the performance of goal-2 where trainees of this group developed erroneous plans and misconceptions. Clearly, some form of 'learning by guided discovery' would have facilitated performance to a large extent, since trainees would have benefited from the development of 'system exploration' rules. Practice effects were anticipated to a limited extent, since the pattern of group performances in trial-4 has only partially supported the third experimental hypothesis. The procedures-group improved its performance significantly and trainees appeared to be in a better position to adapt their responses to the new context. Therefore, learning in an interactive environment compensated to a certain extent for the fact that this group did not receive any form of planning or conceptual knowledge.

The major research question that 'task elements similar in form will prompt an individual to adopt similar cognitive processes and hence, transfer will be effected' has been supported since all groups performed better than the practice-group in the transfer task in trial-3. However, from the analysis of the individual records of achievement it appeared that some task elements transferred to a greater extent than others. The 'one-to-many mapping' relationship between system prototypes and task elements was a plausible explanation since the strategies for achieving goal-2 were transferred to greater extent than those for achieving goals 1 and 3, which entailed a greater performance flexibility. It is conceivable that the planning knowledge had supported this kind of psychological mechanism, hence, the superior performance of the analysis-group in all of the three subordinate goals.
The last two hypotheses concerned the occurrence of nonspecific transfer. Although the present experiment was designed to control for nonspecific transfer, the differential transfer of goals and the individual differences observed imply that such effects occurred. This can be understood in view of the fact that process control skills are very complex cognitive skills and we cannot constrain development of planning elements and system prototypes. Previous studies which have examined relatively simpler tasks such as paired-associate tasks, perceptual-motor tasks and text-editing skills may have achieved control for nonspecific transfer effects in a better way than the present study. The aim of this study was to enable planning and conceptual knowledge to serve the transfer of task elements in the way described in the model of response learning. Both the analysis- and the model- groups achieved better nonspecific transfer scores than the other groups. In addition, the model-group answered more questions of the diagnostic type than the analysis-group, an aspect of performance which had not been emphasised in the training of the latter group. It appears then, that different types of knowledge can serve one another, an issue which is further elaborated in following sections.

THE ROLE OF HIERARCHICAL TASK ANALYSIS IN TRANSFER STUDIES

The proposed version of HTA can be seen as the first stage in setting appropriate learning conditions to optimise 'internal task' transfer of task elements. The main rationale behind this argument lies in the experimental support of the hypothesis that 'task elements similar in form may prompt an individual to adopt similar psychological processes and transfer will be observed'. It will be recalled that all groups performed significantly better than the practice-group in trial-3. However, the size of transfer cannot be determined by HTA and there is a need to utilise a model of learning which would generate hypotheses about types of extrinsic training information which would enable trainees to benefit the maximum from mastering the original task.

In this section, an attempt is made to revise the way in which HTA can be used in an effective manner in order to redescribe complex industrial tasks into a set of similar task elements which may have potential for transfer. In
cases where task elements entail conflicting behaviours, practice should be
given to the extent that performance becomes 'autonomous' and it does not
depend upon the underlying behaviours in conflict.

In order to identify similar or conflicting task elements, it has been argued
that it would be necessary to take task redescription to the lowest level of
detail where the operator interfaces with the system, and any effort should be
made so that complex plans are decomposed to the level in which they can be
assigned to the different categories of the plan taxonomy. This is a laborious
effort on the part of the analyst since a large number of task steps would have
to be redescribed into smaller ones. However, when transfer of skills is a
major concern of training it is necessary to examine whether task elements
within the competence of trainees may entail similar or conflicting behaviours
with others not being mastered yet. In addition, different types of plans may
seem to be equally effective at a particular level of description and further
decomposition may reveal any subtle differences between alternative plans.
Under these circumstances, some sort of guidelines may be appropriate to
facilitate this process.

The diagram in figure 11.1 can be seen as a sort of decision aid in this process.
It will be recalled from chapter 10, that a more concise description of plans
would be to discriminate between decision plans, sequential plans, cycle plans
and concurrent plans, at the first level. From the experience gained with the
HTA of the distillation column example, it was felt that the first step in the
selection of a plan-category would be to examine whether a decision plan
would be within the trainees competence. Decision plans may require a lot of
expertise since a considerable amount of choice is entailed. The psychological
mechanisms entailed in a decision plan can be summarised as follows: (i)
generate alternative courses of action; (ii) evaluate alternative courses of
action; and (iii) select appropriate sequence of actions. Following the
argument that plans should be considered in terms of their 'difficulty', the
next step would be to examine whether the appropriate plan should be of the
concurrent type (step 2), cycle type (step 3) or sequential type (step 4), and
subsequently revise plan description to adjust the level of difficulty required.

A major implication of the experimental findings is that trainees may try out
alternative plans before they master a more demanding plan. An example
would be the performance of time-sharing plans such as 'adjust level-1 in
Figure 11.1. A decision aid to identify appropriate types of plans during task redescription.
column and product qualities at the same time' which was first tried out as a
fixed cycle plan. It appears that expertise develops through a smooth shift
along many plan categories until the specified category is mastered. Support
for this argument is provided by the observations made in chapter 10, about
between-category transfer of plans. Three main factors have been identified
as likely to affect the process of plan transformation at different stages of
learning, that is, conceptual knowledge, planning knowledge and opportunistic
performance (e.g. 'rules of thumb'). Clearly more research is needed to
examine this process in experiments which would control for the effect of
these three factors.

A related issue is the problem of plan recognition, since trainees may appear to
practise different types of plans during the performance of a task, and it
becomes difficult to assign those to a single category. The present study had
certain limitations since a compromise was made that only the plan types with
the greatest frequency of occurrence would be taken into account.

The issue of the relative degree of transfer of different types of plans has also
been highlighted. It is conceivable that when trainees understand the goal-
relationships entailed in a plan, transfer will be optimised. However,
transferability of each plan-category will be affected by a number of factors
such as level of plan in the HTA of the task, size of valve adjustments etc.,
which were not rigidly controlled in this experiment. An interesting finding
of this study was that certain forms of extrinsic information such as planning
knowledge and possibly conceptual knowledge can serve the issue of transfer of
plans.

ELABORATIONS ON THE 'GOAL RESPONSE SET DISTANCE' MODEL OF
LEARNING

The model of learning which has been developed in chapter 5, will be further
elaborated in view of the experimental findings so that it becomes a useful
tool for generating hypotheses about both specific and nonspecific transfer.
In this section, the following aspects will be discussed: (i) interaction between
constituent response items; (ii) contribution of response items to the
performance of different types of tasks; and (iii) integration of response
management and explanation building activities.
Interaction between constituent response items

The proposed 'Goal Response Set Distance' model of learning assumes that performance may be affected by three types of knowledge, namely, task elements, planning elements and system prototypes. It is conceivable that these types of knowledge or response items are interrelated, however, the type of underlying relationships need to be made explicit so that models of learning have the capability of generating transfer predictions. Many of the comments which follow are of a tentative nature only, since their sole source of qualification was the individual records of achievement.

The relationship between system prototypes and task elements has been illustrated in their 'one-to-many mapping relationship' mechanism of transfer; it may appear that the greater the number of task elements consistent with a system prototype, the smaller the likelihood of transfer of task elements will be, in the absence of any additional training information. On the other hand, development of system prototypes is affected by the process in which task elements are mastered. Performance of the procedures-group at the transfer task, for instance, has shown that when trainees are not actively engaged in mastering these task elements, only a limited number of relationships between process parameters is understood; this is in contrast to the erroneous relationships which may be inferred, if practice is the only type of training condition offered.

The same reciprocal relationship can be found between planning and task elements. Planning elements may enable trainees to analyse the task at hand in terms of different types of goal-relationships and be able to modify previously acquired task elements so that transfer is optimised. On the other hand, the process of mastering various task elements will affect development of planning elements. It may be argued that 'active' learning will optimise this aspect of performance as the practice-group had a better Planning Elements Score (PES) than the procedures-group in both transfer tasks.

The other type of relationship between planning elements and system prototypes cannot be easily elaborated, since nonspecific transfer was a peripheral issue in this study. An implication of the results, might be that knowledge of goal-relationships can also be acquired through the teaching of system prototypes. However, there is always an associated risk that not all trainees will manage to achieve this, while even the most competent ones may
not be entirely consistent in using these goal-relationships during their performance. On the other hand, planning elements may also support development of system prototypes to the extent that trainees learn how to explore the system through a set of well-established 'system exploration' rules. These considerations should be traded-off, taking into account resource requirements of these types of knowledge e.g. system prototypes may require a larger amount of time to be mastered than planning elements.

The role of different response items in the performance of various types of tasks

This study has primarily been concerned with the contribution of response items to the performance of tasks sharing a number of task elements; however, as the 'Goal Response Set' distance increases e.g. in unfamiliar tasks, the role of these response items may change as well. In order to examine this relationship, a classification of different types of tasks is needed. The distinction between familiar specific tasks, familiar general tasks and unfamiliar tasks suggested by Bainbridge (1989) might be appropriate in this context. Bainbridge (1989) has argued that, in familiar specific tasks performance may rely upon a set of standard methods dealing with frequent or recurring specific situations, in comparison to familiar general tasks where a set of classified types of activities provide a framework to guide performance. Finally, unfamiliar tasks entail a process of response construction where the trainee is faced with a large 'Goal Response Set' distance.

Figure 11.2 shows that task elements make their greatest contribution to performance in familiar specific tasks e.g. trials 1 and 2. When the emphasis of training is placed upon transfer to familiar general tasks, the role of planning elements becomes more important, whereas at some stage, system prototypes become more important than task elements e.g. trial-3. With the increase of practice, however, the task becomes more specific and the latter two types of knowledge may be of equal importance e.g. trial-4. In unfamiliar tasks, however, the role of system prototypes becomes increasingly important as trainees need to possess a good knowledge of 'how-the-system-works' which expands beyond the requirements of the task elements mastered so far. It may be argued, therefore, that system prototypes may be of equal importance with planning elements, as far as nonspecific transfer is concerned.
Figure 11.2. Contribution of response items to the performance of different types of tasks.
These trends in the importance of different response items in figure 11.2 are best descriptive when a 'first-shot' transfer paradigm is adopted. When the concern is on 'saving' measures of transfer, practice effects on the transfer tasks should be also taken into account. A tentative suggestion might be that with the increase of practice on a familiar general task or unfamiliar task, the trends may be interpreted in the opposite direction as it is indicated by the arrow in figure 11.2. This is, indeed, an interesting research question which need to be addressed in future transfer studies.

Integration of response management and explanation building activities

The proposed model of learning has a strong 'response management' orientation and has not thoroughly addressed issues of 'explanation building' activities taken by trainees such as assessing the situation and self-monitoring of one's progress. Explanation building is part of the learning process and a series of studies in the text-editing domain (Lewis and Mack, 1982; Mack et al., 1983; Riley, 1986) have indicated that learners are able to devise explanations which can make the effects of even disastrous errors seem reasonable. As a result, learners may sometimes continue working without any attempt to correct errors, since they may explain them away. A similar phenomenon was observed with the trainees of the practice-group who developed erroneous plans and misconceptions about the functioning of the plant.

Although a number of different types of instruction have been suggested to aid this process of explanation building such as 'knowledge of goal-relationships', 'rules of thumb' to explore the system, and elaborate prototypes of the functioning of the system, it is a bit unclear how these activities become integrated with the response management activities such as response selection, adaptation, construction etc., particularly with the increase of the complexity of the plant. To some extent, the present experimental design may have concealed some of these issues, since the tested tasks shared a large number of task elements and the complexity of the system was tailored to the abilities and experience of the subject population.

There is a need, however, to address more systematically questions such as 'when, how often, and to what extent trainees need to assess the situation before a solution to the problem is found'. It is conceivable that a different
experimental paradigm may be needed, whereby a large number of training exercises are designed which are not pre-occupied with quantitative aspects of performance such as speed, accuracy and economy of operation. The present study was limited in this respect, and certain attempts were made to redress the situation by examining the individual records of achievement. Since, a concern was placed upon not interrupting trainees performance, these considerations gained a limited insight. Clearly, more studies of the proposed kind are needed to elaborate on these aspects of learning.

INSTRUCTIONAL DESIGN IN A SYSTEMS CONTEXT

The present study has focused on the role of extrinsic training information upon transfer of skills based upon a proposed model of response learning. However, a number of other instructional components such as response facilities, feedback, level of task abstraction, learning styles etc., which have a significant effect on performance were not investigated. The systems approach to training looks at the different functions of the instructional components and examines their relationships and their effect upon the outcome of performance. In the long run, this might be a more efficient approach, if carrying out an experiment to determine the most appropriate training method is not practical. Running small pilot schemes with a sample of trainees might be a more cost-effective methodology than designing rigorous experiments which investigate limited aspects of performance, particularly when the systems approach to training can be implemented in a computerised form.

Following the outline of training ideas intended in the view of learning described in this thesis, a system for controlling and delivering instruction has been proposed by Shepherd and Kontogiannis (1987). Figure 11.3 shows an 'adaptive training system' which conforms in many aspects to ideas suggested in the training literature such as Eckstrand (1964) and Becker (1987).

Stage-1 entails selection of a task 'criterion model' which defines what the trainee is required to master. This would be supplied in the form of a modified HTA as specified in chapter 3.
Figure 11.3. A model of instruction by Shepherd and Kontogiannis (1987).
Stage-2 chooses the part of the task to be mastered, which entails selecting a goal and a set of response facilities. This implies deciding how great a learning challenge to set the trainee e.g. choosing a 'Goal Response Set' distance. It is likely that the same starting point will be adopted for each trainee in the absence of further information. With the progress of learning, a record of competence is built-up which provides input to stage-2. This record relates to the criterion model in stage-1, indicating what the current learner has already mastered and it uses the evidence of observed performance to infer likely transfer of training.

Stage-3 is concerned with adjusting conditions for the trainee to practise the task elements selected in stage-2. It includes:

1. Setting the new goal to the trainee;
2. Providing the appropriate response facilities;
3. Adjusting extrinsic information;
4. Adjusting the amount and type of feedback to the trainee;
5. Adjusting the manner in which the plant is represented; and,
6. Selecting and adjusting the events the trainee is required to deal with.

The model of response learning and record of competence will determine the range of choices for each of these.

Stage-4 is concerned with monitoring pertinent aspects of performance such as making correct choices or actions, productivity, timing of responses etc. Stage-5 provides feedback to the trainee as this has been specified in stage-3. Stage-6 uses information gained in stage-4 to update the record of competence. As the learner demonstrates capability, so the instructor should infer all of the aspects of the learner record which need updating; this is the 'common elements' transfer issue discussed earlier.

The 'control mechanism' continues from stage-2 again, but now more is known about the trainee since the record of competence has been updated in accordance with the predicted transfer effects. While a few rules can be suggested, more research is needed to examine their validity and establish a mechanism for resolving conflicts between them. Rules will be of the type:

- If the trainee has nearly mastered a goal, then repeat the exercise;
If the trainee has been taught some extrinsic information, and there are task elements that would benefit from the same information, then present one of these elements;

If the trainee has demonstrated mastery of a goal move to a different goal to avoid over-training (unless stereotyped responses are required).

The proposed adaptive training system can be used to indicate future research areas which need to be addressed in order to understand the relationships of the various instructional components and their effect upon the learning process.

**DIRECTIONS FOR FUTURE RESEARCH**

While the present study has provided some useful insights into the role of training methods in the transfer of skills, it might appear that more research questions have been raised than the ones actually tested. In particular, further research is needed to highlight the following issues.

1. There is a need for running small pilot schemes in order to examine the interrelationships between the various instructional components entailed in an adaptive training environment. Issues which deserve more attention as such should be systematically investigated by rigorous laboratory experiments. Whereas certain training methods might be more appropriate than others, there is nothing to constrain an instructor implement a combination of those, taking into account criteria of cost-effectiveness as well as different learning styles of operators. The point of 'changeover' between various training methods needs further investigation, and the systems approach to training previously described may provide an appropriate context for it.

2. Transfer to unfamiliar tasks was a peripheral issue in the present study, and our knowledge of nonspecific transfer needs further development. As operators take a supervisory role in complex industrial systems with the increase of automation, problem-solving skills and functionally reasoning skills (Rasmussen, 1986) will be increasingly on demand. A first step in this direction would be to further explore the development of planning elements
and system prototypes respectively, in unfamiliar situations. Performance in tasks entailing a large 'Goal Response Set' distance needs further investigation.

3. Related to this issue is the process of 'response construction' which has been addressed in the model of response learning. In order to understand this process, we need to examine the way trainees construct responses from items within their repertoire as well as through modelling the task at an intermediate level using sub-ordinate goals.

4. Also warranting attention is the integration of response management and explanation building activities in the learning process. Task characteristics and conditions of learning which may affect the way trainees assess the situation before seeking a solution to the problem and explain their progress need to be considered. The development of 'system exploration' rules and elaborate prototypes of the system is a first step in this direction. Research by Woods et al. (1987) is under way to investigate the role of task characteristics e.g. degree of uncertainty and risk, highly coupled systems, dynamic systems etc., in the process of response management and explanation building.

5. The present study has investigated, to a certain extent, the issue of between- and within-category transfer of plans. However, a number of influencing factors such as level of plan in the goal-hierarchy, planning and conceptual knowledge, and opportunistic performance need to be evaluated in a more systematic way, particularly when quantification of transfer is a major concern.

6. The role of individual differences in training design is another issue for research. It is worth noting that some trainees may favour certain training methods rather than others, and the question of which training method is the most effective may become an impractical one, if learning styles are not paid attention. HTA provides a framework for selecting task elements at various levels of detail to take into account the learning styles proposed by Pask and Scott (1973), and Pask (1975) e.g. 'wholistic' versus 'serialist' learners.

7. Most studies in training design have confined themselves to examining performance at the initial stage of learning. Relatively little is known about training 'expert' operators. A tentative suggestion made in the context of the model of response learning was that experts may need to master a useful set of
intermediate skills, then practise them on varying goals such that the higher level goals are never actually compiled as responses in their own right. This generalisation needs qualification from appropriate transfer studies.

Therefore, the issue of transfer of skills in many respects continues to raise research questions. The present study have tackled some of them and some generalisations were made. The magnitude of the debate is illustrated by the limited extent to which this has been possible. Progress towards the study of skills will be gradual, since human learning is a complex affair and past experience shows that we should not expect simple answers.
REFERENCES


Bunch, M. E. and Lang, E. S. (1939). The amount of transfer of training from partial learning after varying intervals of time. Journal of Comparative Psychology, 27, 449-459.


APPENDIX 1

ANALYSIS OF VARIANCE TABLES
### Table 1.

**Analysis of variance for the number of runs spent to perform the original tasks, (trials 1 and 2).**

<table>
<thead>
<tr>
<th>SOURCE</th>
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Table 2.

Analysis of variance for the time spent to perform the original tasks, (trials 1 and 2).

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Table 3.
Analysis of variance for the number of runs spent to perform the transfer tasks, (trials 3 and 4).

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Key:
B1: trial-3;  B4: trial-4;
A1: model-group;  A2: analysis-group;
A3: procedures-group;  A4: practice-group.
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Table 5.

Analysis of variance for the overall control performance at the original tasks, (trials 1 and 2).

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Table 6.

Analysis of variance for the overall control performance at the transfer tasks, (trials 3 and 4).

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Key:
B1: trial-3; B4: trial-4;
A1: model-group; A2: analysis-group;
A3: procedures-group; A4: practice-group.
Table 7.

Analysis of variance for the normalised total energy consumption at the original tasks (trials 1 and 2).

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<td>Subjects within groups</td>
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<td>2862.10</td>
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<tr>
<td><strong>Within subjects</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>Trials (B)</td>
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<td>3</td>
<td>20003.49</td>
<td>6.99</td>
<td>p&lt;0.01</td>
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<td>(A X B) Interaction</td>
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<td>Trials X subjects within groups</td>
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Note: p=N.S indicates the probability is not significant.
Table 8.

Analysis of variance for the normalised total energy consumption at the transfer tasks (trials 3 and 4).

<table>
<thead>
<tr>
<th>SOURCE</th>
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<th>Probab.</th>
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<td>Methods (A)</td>
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<td>Trials (B)</td>
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Table 9.

Analysis of variance for the Planning Elements Score at the transfer tasks, (trials 3 and 4).

<table>
<thead>
<tr>
<th>SOURCE</th>
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<tr>
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### Table 10.
**Analysis of variance for the Correct Answer Score at the overall questions.**

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### Table 11.
**Analysis of variance for the Correct Answer Score at the compensatory questions.**

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<tbody>
<tr>
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### Table 12.
**Analysis of variance for the Correct Answer Score at the diagnostic questions.**

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<td>Error</td>
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<td>Total</td>
<td>3783.48</td>
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APPENDIX 2

AN ANALYTICAL PERSPECTIVE IN THE OPERATION OF THE DISTILLATION PLANT
2.1. INTRODUCTION TO THE DISTILLATION PROCESS

2.1.1. The purpose of Distillation

Distillation is a process in which a liquid mixture of two or more substances is separated into its component fractions of desired purity by the application and removal of heat. Distillation columns are widely used in industry, particularly in the petroleum industries for the separation of crude-oil components. They are also used for the production of alcoholic beverages.

The present plant is designed to separate a liquid mixture which consists of 30% acetone and 70% water. By the application of heat to a liquid mixture of water and acetone, the vapour so generated will be richer in the liquid with the lower boiling point (i.e. acetone). Subsequently, if this vapour is condensed, a certain amount of purification will have been achieved. This is the underlying principle of distillation.

2.1.2. The operation of a distillation column

The design of a typical distillation column is shown in figure 1. Let us consider how the column operates. Assume that the feed is a binary liquid mixture of 30% acetone and 70% water (percentage in weight) which enters the central portion of a vertical tower and fills up the base of the tower to a certain level. The liquid from the base of the tower flows into a heating device (reboiler), where it is partially evaporated. The liquid which is not evaporated is removed from the reboiler and collected at the bottom section of the column (bottom product).

Since acetone has a lower boiling point than water, the vapour generated in the reboiler will be richer in acetone than the bottom product. The vapour rises up the tower and enters a cooling device (condenser) where is fully condensed into liquid which is collected in a storage tank (drum). This liquid mixture (top product) is more concentrated in acetone than both the feed and the bottom liquid. This is the first stage in the operation of the plant which involves only one stage of purification. In order to further purify the top and bottom products, a second stage is needed.
Figure 1. A schematic of a distillation column.
In the second stage, part of the top product flows back into the top of the tower (reflux flow). This liquid coming down the tower fills up a number of trays which are mounted inside of it. Eventually, they overflow and liquid flows down to the tray below (see figure 1). In the present plant, there is only one tray at the top of the tower to make the operation relatively simple.

The rising vapour mixture bubbles through the liquid mixture on each tray. During this contact of vapour and liquid, the hot vapour evaporates some of the liquid (partial evaporation), while the cold liquid condenses some of the vapour (partial condensation). Again because of the difference in the boiling points, it is acetone which evaporates first out of the liquid (acetone is the light component) and water which distils first out of the rising vapour (water is the heavy component). This means that the vapour which passes through each tray is richer in acetone than the vapour below the tray. When the overhead vapour is fully condensed in the condenser, a greater amount of purification is achieved than the one in the first stage. Thus, we can see that in the second stage there are two stages of purification: one in the reboiler and the other in the trays.
2.1.3. ADJUSTING FLOW-RATES, LEVELS, COMPOSITIONS AND TEMPERATURES DURING PLANT OPERATION

(i) Adjusting flow-rates
The flow-rate of a liquid in a pipeline will be determined by the capacity of the pump and the position at which the valve is adjusted. Since the capacity of all pumps cannot be changed within the same trial, the flow-rate can be adjusted by changing the position of the valve only. This does not necessarily mean that when two valves are adjusted at the same position the two flow-rates will be equal, since the capacities of the pumps may be different.

(ii) Adjusting levels
The level in the base of the tower or drum indicates the quantity of the liquid inside. Changes in the flow-rate of the input and output flows result in changes in the level according to the following formula:

\[ \text{level-change} = \text{input flow rate} \times \text{output flow rate}. \]

Note that the static pressure of the liquid above the exit pipeline would be negligible compared to the pressure of the pump; therefore, the level in a tank will not affect the output flow-rate.

(iii) Adjusting the composition of a liquid mixture
The following example will illustrate how to adjust the composition of a liquid mixture in a tank. Supposing there are 50 Kg of a liquid mixture of 30% (in weight) in acetone in a tank, and that we try to change its composition by feeding 2 Kg/min of a liquid of 80% (in weight) in acetone. It can be proved that, in every minute, we cannot change the composition of the liquid in the tank by more than 2%-3% in acetone. This is because of the relatively small quantity of the feed (2kg) entering the tank, compared to the quantity of the liquid already in the tank (50kg). If the tank has also an exit flow, this will speed-up the process of changing the composition, because a certain amount of liquid of the old composition would leave the tank.

Note that the recorder of the composition of the bottom product takes readings from the pipeline at the exit of the reboiler, while the one of the top product from the drum, which is different than the composition of the liquid at the exit of the condenser.
(iv) Adjusting the temperature of a liquid mixture
The temperature of a liquid in a tank will be affected in a similar way by any changes in the temperature of the feed. Because the amount of liquid in the feedflow is relatively small compared to the amount of liquid already in the tank, any increase in the temperature of the feed will take some time to increase the temperature of the liquid in the tank.
2.2 TRAINING INFORMATION PROVIDED TO THE 'MODEL' GROUP

2.2.1. VAPOUR-LIQUID EQUILIBRIA

When a liquid mixture is brought into boiling, the produced vapour comes into equilibrium with the residual liquid in a way that their compositions can be determined from the liquid-vapour equilibria curve in figure 2.

Suppose that a mixture of acetone and water is continually circulating a reboiler or condenser and that we supply or remove heat at various rates by adjusting the flows of a heating or cooling agent. When we supply heat at a low rate, evaporation will start at point A (see figure 2), when the heat is large enough to bring the temperature of the mixture at the 'bubble-point'. Because acetone evaporates first from the liquid, the produced vapour becomes richer in acetone while the residual liquid becomes a bit poorer than the original liquid. With the increase of heat supply (point B), greater amounts of vapour are produced which contain more acetone than before, however their proportion in acetone becomes smaller than before, but still greater than the one of the original liquid. As a result smaller amounts of residual liquid are produced which are less concentrated in acetone.

Finally, when the rate of heat supply is extremely large (point C) and the amount of the original liquid is relatively small, all the liquid can instantly be transformed into vapour. In this case, the produced vapour will have the same composition with the original liquid. In summary then, the produced vapour will be in equilibrium with the residual liquid at different compositions, corresponding to different rates of heat supply.

(i) Complete evaporation
Complete evaporation cannot be used to separate the components of a liquid mixture, since the composition of vapour will be the same with the one of the original liquid.

(ii) Partial evaporation
We saw that when only part of the liquid mixture evaporates (point B), the vapour becomes richer in acetone than the original liquid. Hence, 'partial evaporation' can separate the components of a liquid mixture and this constitutes the underlying principle of the reboiler.
Figure 2. Vapour-Liquid Equilibria.

**Key**
- [ ] [%] water;
- [ ] [%] acetone.

*Greater amount of liquid*

*Lesser amount of vapour*

*Rate of heat supply*

*Rate of heat removal*
(iii) Complete condensation

When vapour is cooled down in a similar device, condensation starts at point C and it progresses backwards to point A with the increase of heat removal. As we remove heat from the original vapours at greater rates, a point A is reached where all the vapour is transformed instantly into liquid of the same composition. This can only happen when the amount of the original vapour is relatively small. The purpose of the condenser in our plant, is precisely to achieve 'complete condensation' of the original vapour so that all acetone contained in the vapour can be collected in liquid form.

(iv) Partial condensation

'Partial condensation' brings about enrichment of vapour in acetone in the same manner as 'partial evaporation'. When vapour is partially condensed (point B), the produced liquid is not as much rich in acetone as the original vapour, while the residual vapour becomes richer in acetone. These two processes occur during the mixing of the rising vapour and the down-coming liquid in the trays of the column, bringing about enrichment of vapour in acetone.

As a 'rule of thumb', it is worth noting that 'as the amount of vapour increases, the composition of both the vapour and liquid in acetone will decrease'; the reverse is also correct.
2.2.2 MASS/ENERGY TRANSFER IN THE REBOILER

The reboiler is a heating device in which a liquid mixture is partially evaporated and the produced vapour becomes richer in the lighter component e.g. acetone, than the original liquid. In order to achieve the required amount and quality of vapour and bottom product, the following process parameters can be controlled: (i) the feedflow of the product, by adjusting valve Yo, and (ii) the flow of the heating agent, by adjusting valve Vb.

Figure 3 shows the input and output flows in the reboiler as well as the process parameters which can be controlled either directly or indirectly. In section 2.2.1, we have discussed the behaviour of the system when the heat supply changed under constant conditions of the feed product. However, it is worth considering other ways of controlling the system such as changing the flow-rate and composition of the feed product. In specific, when the flow-rate of the feed is increased, a smaller amount of vapour will be produced, whilst the composition (% in acetone) of both the vapour and bottom product will increase. On the other head, when the composition of the feed is decreased, the composition of both output products will also decrease.

2.2.3 MASS/ENERGY TRANSFER IN THE CONDENSER

The condenser is a cooling device in which vapour is transformed into liquid. In our plant, the incoming vapour should be completely condensed, so that the produced liquid is as much rich in acetone as the original vapour was. It is only the flow-rate of the cooling agent which can be controlled in the condenser by adjusting valve Vc. However, we can control the flow-rate and composition of the incoming vapour by adjusting all the parameters upstream the condenser; obviously, this indirect mode of operation is very difficult since a great amount of experience is required so that the previously established parameters are not disturbed.

An interesting operational difference between the condenser and reboiler stems from the amount of products they process in a cycle; for safety reasons, the plant is designed in such a way that complete condensation can be achieved with a minimum amount of energy, whilst complete evaporation requires much more energy.
Figure 3. A Schematic of a reboiler.

Feed Liquid Product

(Flow-rate, composition)

REBOILER

Vapour

(Flow-rate, composition)

Bottom Liquid Product

(Flow-rate, composition)

Heating Agent

(Flow-rate only)

KEY

1 = input flow; 0 = output flow.
2.3. QUESTIONNAIRE

Please answer the following questions:

1) Which flows directly affect the composition of the bottom product?

2) Which flows directly affect the composition of the top product?

3) How can you decrease a high pressure?

4) Suppose that Vb and Vc have stuck in the positions you see and that the pressure is very high; what would you do to relieve the pressure?

5) Suppose Vd has stuck in the position you see; how could you increase the level in the drum quickly?

6) Suppose Vd has stuck in the position you see; how could you get closer to the specification of the top product?

7) Suppose that the reflux flow increases substantially; what symptom would you observe?

8) Suppose that Vo has stuck fully open; what symptom would you observe?

9) Suppose that Vb has stuck fully open; what symptom would you observe?

10) Suppose that Vc has stuck fully open; what symptom would you observe?