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# SKILL RETENTION AND CONTROL ROOM OPERATOR COMPETENCY

by

R. B. Stammers

Report No. 19, December 1981

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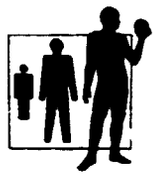
## SUMMARY

The problem of skill retention in relation to the competency of control room operators is addressed. Although there are a number of related reviews of the literature, this particular topic has not been examined in detail before. The findings of these reviews are summarised and their implications for the area discussed. The limited research on skill retention in connection with process control is also reviewed. Some topics from cognitive and instructional psychology are also raised. In particular "overlearning" is tackled and the potential value of learning strategies is assessed. In conclusion the important topic of measurement of performance is introduced and a number of potentially valuable training approaches are outlined.



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## INTRODUCTION

The traditional view of training in many job situations is that the skills and knowledge acquired during the training period will continue to be practised in the job situation, leading to even higher levels of proficiency of the "skilled person". At the end the graduate of the training will move into an on-line situation which closely resembles that for which training was received. The job itself then puts a constant and frequent demand upon the tasks practised within training.

There are, however, other sorts of jobs that have certain important differences, e.g. jobs where the human operator to a large extent acts as a monitor and/or back-up system. This is the sort of situation found in power generation plants and in a number of other jobs which involve supervision of highly automated processes. With reliable plants, many task aspects will not be frequently practised and some aspects may never be called upon. The operator may be required to make periodic adjustments to the plant or may be required to log the readings on instruments, but the important tasks of start-up and shut-down and the all-important tasks of problem diagnosis and rectification will necessarily be infrequently practised. It is not surprising therefore, that there is concern over the retention of knowledge and skills acquired during training. It is recognised that the human operator is fallible, knowledge gained at one point in time may not necessarily be available at some future date. The problem is acknowledged and provision of such activities as continuation training, refresher training, re-training and re-licensing and testing procedures support the idea that the human memory does not function in the same way as a computer memory, but the important research questions have not received sufficient attention.

The purpose of this report is to re-address this problem in the particular context of control room tasks. It is not proposed to survey the literature in detail as a number of reviews are available. Instead the possible relevance of this previous work to the current problem will be reviewed. In addition, other areas will be explored that are felt to be pertinent to the problem. In particular, these areas concern developments in cognitive psychology and instructional technology.

It is useful to examine the practical issues behind the previous reviews as they differ somewhat from the concern of this report. It is also important to point out at this stage that most reviews of skill retention have concentrated on what have been termed perceptual-motor skills. These usually involve manual tracking tasks or procedural tasks of various kinds. The emphasis therefore has been on perceptual interpretation of displays and the manipulation of controls. The literature was reviewed by Naylor and Briggs (1961) with particular concern over the retention of the skills for aircraft control tasks. Practical problems here concerned such issues as the retention of re-entry skills following prolonged space flight. This particular topic has been followed up in more recent years with the development of the American Space Shuttle which has put more emphasis on the piloting skills of astronauts (Gardlin and Sitterley, 1972). In the aviation area in particular, there has always been concern over the

retention of landing and take-off skills which would be infrequently practised and of course, emergency procedures. This topic is of concern in both the civilian area and the military area (Prophet, 1976a, 1976b). In the military context there is concern over skill retention for a number of reasons. In high technology tasks, such as aircraft control, training is expensive and training flights are necessarily kept to a minimum. There is concern however, over the retention of such skills without frequent practice. Commercial pilots undergo frequent retraining exercises in simulators. With military tasks in general there arise a number of practical problems concerned with the cost of training and the need to keep it to the minimum, at the same time there is the need to maintain skills at a high level of readiness (Schendal et al., 1978).

Another source of interest on this topic, has arisen from industrial training problems. In the U.K., for example, there has been the policy in recent years of giving training to people who are unemployed. At the end of that training, there may not be immediate employment prospects. As part of the national manpower programme the need to have resources of skilled labour has been voiced, but again there have been worries over the extent to which such training will be retained over some years of unemployment (Annett, 1977, 1979).

The closest previous research to the main topic of this report, that of the retention of infrequently practised control room tasks, is that derived from the area of maintenance training. This somewhat parallels the control room situation in that the maintenance trainee will receive both general and specific training and then be expected to act as a fault finder and rectifier, usually for a range of pieces of equipment that will be encountered, at perhaps infrequent invervals, during work. This topic has been researched to a limited extent, mainly in the military context. Research has shown that the theory learned in training is particularly vulnerable to forgetting (Johnson, 1969). This brings us to our current topic that of control room tasks. This problem of retention has been recognised, (Duncan, 1971 and 1974), but has not been researched in detail. Some suggestions for training methods to enhance retention have been made (Shepherd, 1977).

Most of the reviews have concentrated on laboratory studies of skill and have examined the nature on skill retention over time. They have provided a number of useful generalisations about skill and the time course of its retention. Another approach which has not been developed to any great extent is to examine various forms of training and to determine to what extent they were effective in maintaining skills. It is to this end that this report will address some wider issues in instructional technology and branch out into some other areas of study. In particular, some earlier work on the best instructional methods for retention will be mentioned. Also emerging topics in what is shown as the 'learning strategies area' will be examined. Finally, attention will be given to the sorts of training technology that could be exploited in order to enhance the retention of these key skills. Training technology in this sense includes both the training methodology, in terms of the organisation of training and rehearsal techniques, and the particular sorts of hardware and software that might be used within training systems.

## PREVIOUS WORK

It is not intended in this review to cover the numerous methodological problems in the area. There are many problems inherent in long term memory studies, problems of measurement, problems of comparing widely differing tasks and the problems of experimental design. The issue of methodological difficulties will be returned to at a later stage when studies in an applied setting are discussed. As mentioned above there have been a number of reviews of previous research in this area (Naylor and Briggs, 1961; Gardlin and Sitterley, 1972; Prophet, 1976a, Annett, 1977; Schendal et al., 1978). They are in the main concerned with perceptual motor skill situations and the obvious limitations of this work should be recognised. The major findings in the area can be summarised as follows:

a) The magnitude of skill loss over time depends upon a number of factors. Whilst for some tasks quite high retention is obtained, other studies can be cited that show a serious deterioration over a period of months. For example, Fleishman and Parker (1962) found only small performance decrements for a tracking task over a two year retention period. On the other hand, Cotterman and Wood (1967) reported a significant decline in a simulated space-craft control skill after a week of non-practice. Following a six-week period without practice, Vineberg (1975) found decrements of between 18% and 26% for a range of military tasks, e.g. military drills, first aid and weapon handling. Hagman (1979) has demonstrated that for typewriting skills a decrement of 25% in speed and an increase of errors by 86% can occur with a period of non-practice of between 14 and 38 days.

b) The nature of tasks is a key variable, although the old generalisations that continuous motor skills are well retained whilst procedural motor performance is not, would appear to be an over-simplification. Studies have shown significant deterioration in some motor skill tasks. The comparison of tasks illustrates one of the methodological problems in the area. This is particularly so when it becomes difficult to determine the relative levels of learning of different types of tasks. An idea introduced by Naylor and Briggs (1961) was that a more important variable may be that of task organisation. The suggestion is that tasks with high inherent task organisation will be better retained than those without, high organisation referring to patterning in the task, or the degree of predictability of one aspect to the task to another. Thus, a highly predictable tracking task will be better retained than one with random inputs and therefore low organisation; the same principles apply to procedural tasks with differing degrees of task organisation. This variable would also presumably interact with the level of learning, the degree of organisation imposed upon the situation by the learner will also influence the degree of actual organisation perceived by the learner. Experimental support for this idea is in general positive (Gardlin and Sitterley, 1972) but the case is not conclusively proven (Annett, 1977).

c) The amount and kind of original training is clearly an important variable in this area. A number of studies have shown that skill retention is directly related to the total amount of training received. Studies comparing retention following differing amounts of training lend support to this notion (Trumbo et al., 1965; Hammerton, 1963). One of the few training principles to emerge in this area is that overtraining should be given whenever a situation of skill retention presents itself. Whilst this maybe so in some of the simplified or abstract skill situations it is a major problem that will be readdressed later in this report.

d) The nature and frequency of rehearsal training or re-training are also key factors. This has practical implications for the organisation of re-training but as yet the findings are based on a limited number of experimental perceptual-motor skill studies. For example, experiments by Naylor and his associated (Naylor et al., 1963; Naylor and Briggs, 1963) showed that skill loss could be countered by the use of various forms of training during the retention interval. Annett (1977) reviews this and other work and points out that it is useful in that it suggests that limited rehearsal during the retention period can prevent major skill loss.

e) Related to the above points, is the finding from a number of studies that re-learning following a period of non-practice if frequently very rapid. The previous levels of skill often being re-attained with a limited amount of retraining.

f) Again related to the above two points, is work that has shown effective retraining using quite low realism training situations. Examples of these would be imagery techniques and low fidelity simulators. For example, Sitterley and Berge (1972) and Sitterley et al., (1972), in studies related to the space shuttle programme, showed effective training from low fidelity training devices. Other studies, such as those by Naylor et al., showed some gains to be obtained from practice on part of the task only. In addition studies by Grimsley (1969a, 1969b) have shown effective rehearsal from practice on a procedural task using a low fidelity simulator.

Results of this research are important in two ways, even though their findings are not directly applicable to the control room situation. Firstly, on the negative side, it has been demonstrated that even with abstract, or fairly simple, perceptual motor tasks, skill loss over time is to be expected. On the positive side it shows that such skill loss can be tackled by appropriate rehearsal techniques. Such rehearsal training need not necessarily involve the full task demands in order to be effective.

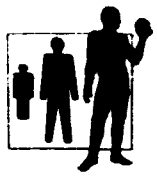
## THE PROCESS CONTROL CONTEXT

Whilst a number of interesting findings exist in the skill literature, it is difficult to make a direct translation of them to the control room situation. The main focus of interest up to now has been on perceptual motor tasks in the aircraft control area. Very few of the cognitively demanding tasks such as those found in control room

situations have been studied. The retention of procedure following tasks is most relevant and of considerable interest given the vulnerability of performance on such tasks to forgetting. The remembering of procedural items is a common feature of control room tasks, but by far the most interest is in the problem-solving tasks of fault diagnosis, fault isolation and fault rectification. Whilst in the procedural task area performance can be supported by things like job aids, it is the cognitive skills that are most difficult to aid in a similar way. In addition, even if aids can be provided for fault location some initial diagnosis of a situation has to be made in order to know which procedural guides to select.

This question has been addressed to a limited extent by workers in the process control area. A useful analysis of the situation and some empirical work is reported by Duncan (1974). In examining a task of fault location in a chemical plant, he drew attention to differences in performance following practice with or without procedural guides. Practice with the procedural guide initially supported performance. However, trainees undergoing a second training procedure, where they worked in an unsupported way and were required to determine the nature of faults, gave much better retention. It also led to more transfer of training to a new fault situation. Duncan makes reference to the early work on the transfer and retention of learning. This work demonstrated that whilst specific material undergoes forgetting over a period of time, transfer of learning from one situation to another is much more stable. In subsequent experimental work by Duncan, this idea was given further support. Using the same fault location task as before, he found that retention of the original task over a period of 200 days declined significantly, whereas transfer to a new task remained stable. In a more detailed analysis of these results, he showed that it was the low ability subjects that were particularly prone to forgetting the original task, whilst all subjects showed stability in their transfer scores. The suggestion is that a higher level strategy, applicable to a range of situations, can be learned in the context of a specific task and is well remembered over time. On the other hand, the specific features of the task are more subject to forgetting. This superior retention of strategy may be due to such strategies being inherently better retained. Duncan points out that an alternative explanation is that it is due to extra practice of the strategy versus the specific material, i.e. some aspect of the strategy is practised on every occasion. Nonetheless, these findings are important in their implications for training. It seems that an effective strategy, if this could be developed for a particular task, is more likely to be retained over time than the specific features of a situation. This in turn places an important emphasis on the task analysis in as much as the detailed analysis of any one task must be looked at for ways of providing a general strategy for the various features of that task.

A low fidelity simulator for training in diagnosis for process control operators has been developed by Shepherd (1977). One of the advantages claimed for this device is that it can be used to give training that would be more resistant to forgetting. The low fidelity device uses back projection techniques to present the trainee with life-size photographs of instruments. The advantage lies in being able to present, in rapid succession, pictures of potentially confusable plant instrument readings. In addition, the system allows for intentsive practice at



this task. A full scale simulator would take some time to be put into the various plant states. Thus by focussing on the simulus aspects of the tasks only, practice is enabled on the perceptual side of the task. A further advantage claimed for this system is that by giving intensive practice at these operations overlearning of them is possible. This overlearning is expected to not only combat the loss of skill over time due to forgetting, but also to provide the learner with skill that is more resistant to the effect to performance under stress. This latter point is not a minor one given the very high negative pay-offs in the situation for control room operators. Training that leads to resistance to such stress would be particularly valuable. The need to exercise the skill that has to be retained over a period of time is likely to occur at a time of some degree of stress for the individual. There is thus a double-edged problem of building up performance that is both resistant to loss over time and that enables the individual to cope during periods of high demand.

Within the process control area there is both a recognition and a partial analysis of the problem of skill retention and some interesting suggestions as to how training can be effectively organised.

## OTHER RESEARCH ON RETENTION

Within experimental or cognitive psychology, there is a vast amount of research on human memory (e.g. Baddeley, 1976; Bower, 1977). Indeed the study of memory has been a central topic in psychology since the initial work by Ebbinghaus in 1885. The bulk of the research in this area has been concerned with theoretical implications of memory and has the additional limitation of studying abstract tasks over fairly short time periods. Even within the experimental study of memory it has been recognised that most research has been directed towards short term memory as opposed to the longer term memory that is the subject of this report. Some have got so far as to say that the sort of memory tasks studied in the laboratory place very different demands on the human information processing than typical tasks of real life; in the laboratory more emphasis is placed on the order of presentation of messages than their content. It is not proposed to review this work in detail, instead the terminology and the background of it will be taken for granted in the interpretation of the current issues. On the other hand, things are now moving very rapidly in cognitive psychology and much more complex problems are being examined and more realistic tasks are being utilised. It is important therefore, to monitor developments in this area for their relevance to problems of applied psychology. Some of most obvious generalisations that can be made from the experimental work are that forgetting may occur for a number of reasons. Some workers have suggested decay theories of forgetting, whereby items initially recalled will be lost over time due to random processes within the central nervous system. Other theories of forgetting place an emphasis on the interference of one set of memory representation by the presence of similar material.

Probably one of the most interesting ideas to emerge in this area in the recent past has been the notion that the permanence of material in memory is dependent upon the level of encoding operations carried out on it. This is the "levels of processing" theory of Craik and Lockhart (1972). A low level of processing would be simply circulating material by repetition from short term memory to long term memory. Deeper levels of processing involve more active cognitive processing of the material. In further work on this topic it has been suggested (Craik and Tulving, 1975) that the idea of depth of processing is perhaps better viewed in terms of elaboration or spread of encoding idea. By this is meant the variety and number of interconnections of material with other material is what leads to stronger memory abilities for particular information.

The above ideas are important in that they would call into question the universal value of overlearning by repetition as a major aid to skill retention. Indeed there is some dispute as to whether overlearning of material is effective. A fair amount of work in the verbal learning area lends support to this idea, i.e. that the degree of retention is directly related to the degree of overlearning of material. This generalisation has been supported by a number of studies (e.g. Postman, 1962). The generalisation seems to break down when studies of "meaningful" verbal material are examined. This topic was looked at in detail in a study by Reynolds and Glaser (1964). They studied the retention of programmed instruction in biology, comparing high school pupils who had either repetition of the material at the time of original learning or spaced review of it during the retention period. Measuring retention after a period of weeks, they found that repetition had little effect on retention whereas the spaced reviews led to a greater amount being retained. Other studies have given support to this idea, raising the general question of whether repetition itself is important to learning or whether once learning has occurred within the individual than additional practice is not going to be beneficial (Gagné, 1971). Further support for the benefit of the review of material during the retention interval comes from studies by Ausubel et al, (1968) and Ausubel and Youssef, (1965). This research has important implications for training practice in that it suggests that review material should be an integral part of training in situations where retention of material is required. A study in this area by Gay (1973) examined more closely the temporal position of reviews. In a first experiment, a review either one day, one week or two weeks following intitial learning, was found to produce equivalent performance on a three-week retention test. All groups receiving reviews scored higher than a no-review group. A second experiment, where subjects were given two reviews, showed that the group with the maximum spacing of the reviews gave better performance compared with those who had their reviews quickly after original learning. In these studies the nature of material has been verbal, but has been conceptual in nature, school children or college subjects have been used and the retention intervals have been in periods of weeks.

The research suggests that with material other than straightforward lists and procedures, overlearning tactics are not likely to yield greater benefits for retention. The powerful effect of spaced reviews

however, is a result that needs to be recognised for its practical potential, suggesting that loss of learning over time can be countered by periodic rehearsal of the material.

## LEARNING STRATEGY APPROACHES

Although not directly related to the current concern there are a number of contemporary developments in the cognitive psychology of instruction that warrant attention. Psychologists are examining a number of areas generally called learning strategies in an attempt to improve the three stages of learning that are important to any training programme, i.e. acquisition, retention and retrieval (Rigney, 1978). The influence of cognitive approaches can be seen in that these three areas themselves are delineated and it is likely that different training approaches may be relevant to different stages of the learning process. That is, what may be an effective strategy for original learning may not be so effective for retention. For example whilst a high realism simulator may be necessary for original learning, a low fidelity device may be adequate for effective rehearsal. At the same time, in the measurement of the effectiveness of any training system, it is difficult to determine where its strength and weaknesses lie independently for these separate areas.

The work on learning strategies falls into two main areas, one that concentrates on enhancing the learning of material through strategies that are given to the trainee, the second aims to enhance the instructional process by building into it strategies that are expected to produce more rapid learning. An example from the first area of learning strategies would be the work described by Dansereau (1978). This research studied the extent to which subjects who were given previous training in paraphrasing, question and answer techniques or visual imagery techniques and were able to use this pretraining to enhance their subsequent learning and retention of new material. This work and other studies in the area generally support that the idea that study skills, as a set of strategies given to learners, can improve the acquisition and retention of new material. The relevance of the range of strategies available to different learners and for different materials needs to be more closely studied.

The second line of research is to look for ways of embedding within the training system, techniques that enhance the acquisition of material. One example would be the experiment of Rigney and Lutz (1976), who made use of the imagery techniques in the learning of principles of physics and chemistry The imagery techniques consisted of the used of computer graphics to explain to learners the principles involved. A recent study on a control panel task by Johnson (1981) showed visual imagery techniques to be important in learning and retention using a low fidelity simulator, although not all studies in this area have shown overall beneficial effects of learning strategies (Singer et al., 1979)

This work is important because it places an emphasis on improving the general quality of instructional systems. Whether this improvement will have a direct bearing on the retention of skills is of course

open to question. But it is worth bearing in mind that the retention of perceptual-motor skills literature showed the most potent variable in predicting retention of skill was the level of performance achieved at the end of training. The use of more effective training mechanisms may enable higher levels of performance at the end of the training period, with in turn, higher levels of retention.

## DISCUSSION

It can be seen that the amount of work directly relevant to the question of maintenance of competency of control room operators is limited. Nonetheless, there are a number of important ideas to emerge from the area that are worthy of closer examination. A number of points hinge upon difficult methodological questions or difficulties arising from the nature of the applied problem.

It is important for the users of training systems to gain confidence in the ability to predict performance over time. The main way that they will be able to do this is to improve measurement systems. Measurement at the end of training and measurement at various periods following training and re-training would enable a full analysis of the situation to be carried out. There are practical difficulties associated with such a straightforward approach. There are obvious difficulties of measuring performance in complex systems, difficulties arising from the validity and reliability of the limited number of direct measures that could be taken. In addition there are problems coming from difficulties of getting agreement from all concerned for such measurements to take place. Another issue emerges from the context in which such measurements can be taken; should they be on the plant, in a simulator or in some simulated version of the task, e.g. the talk-through? In order for the topic to progress there is a need for these questions to be tackled in some way. It may well be that direct performance measurement is not the best way in which to approach the problem. Some indirect measurement, perhaps through some assessment of confidence in their ability to work with the plant could be taken from trainees as an alternative.

From this brief review no instant solutions for producing training that is more resistant to loss over time has emerged. There is a need to look very closely at the efficiency of training programmes, which should be a continual demand in such systems any way. If confidence is felt about training currently produced, this needs to be assessed against confidence in the resistance to forgetting of such training. Nonetheless, the literature suggests that some form of rehearsal of training occuring during the retention period should have positive and beneficial effects. Therefore, thought should be given to programmes of training exercises and rehearsal aids that can be given to trainees during the periods between training sessions.

The outline given above takes a somewhat limited view of the training process. In the systems under study, training is not expected to end when trainees leave the training establishment. They are expected to continue to learn about the plant in which they are working, through

day to day contact with it, and from the shared experience of other operators and supervisors. Indeed, it is unlikely that newly qualified trainees would be expected to work unaided in a complex plant. They would be expected to have the support of other operators and trainees and there may well be training personnel in the plant where they are working. To what extent such experience will occur in a controlled, beneficial way as opposed to a fortuitous and accidental way may be a problem. This experience should be linked together with the need for review and rehearsal activities in order to make full use of the situations that arise, i.e. the idea of "planned experience". Thus, whilst a situation may have been suggested of "forgetting" occurring between training periods, at the same time, trainees will also be learning about the plant in new ways and adding to their knowledge of the systems they are controlling. The extent to which one, or other, or both of these processes are occuring does need to be more closely examined.

Through these day to day contacts with plant and continued experience, the knowledge, general theories and rules etc. that the operator has learned, may well be enhanced. At the same time, specific details of procedure may be forgotten. There may well be a conflict between these two aspects of performance in a particular situation. For example, the nature of fault situation may be correctly diagnosed, but its identifying characteristics in relation to other faults forgotten. It may be that particular level of knowledge may be recalled but it may be at too a high level of abstraction to be useful in a particular situation. A middle road may be needed whereby the appropriate level of knowledge is initially given and reviewed periodically by the trainee. It may be best to leave the details of particular procedures to readily accessible and understandable job aids.

It may be that the sort of knowledge the operator needs is such that in a specific situation, the diagnosis that is made can be fairly novel to the trainee, yet is valid for the situation that is encountered. The development of such an appropriate level of knowledge in terms of the current understanding of the human operator is however and open question. The conclusions of this resumé therefore must be that the continued competency of operators needs to be examined more closely in terms of skill retention questions. If however, the situation is felt to be one that needs further attention, there are a number of suggestions as to how training can be enhanced in order to overcome such difficulties. Some suggestions as to how this may be done now follow:

a) The advantages/disadvantages of overtraining need to be looked at. Overtraining in terms of specific drills and procedures is probably likely to have limited benefit, however overtraining in a variety of uses of the knowledge that the operator has gained may well be an appropriate approach.

b) The need for rehearsal and review training is clear, however the frequency and timing of such training needs to be determined.

c) It may be beneficial to give deliberate training in problem-solving skills and to make the trainee aware of some of the fallibilities of human problem-solving. For example the dangers of; a narrow search in problem-solving, focussing on particular

features, and the common characteristics of searching for confirming evidence rather than non-confirming evidence.

d) In addition, some of the contemporary computer assisted learning techniques can be looked at for ways of providing rehearsal or review training. Given that research has shown that practice with low fidelity versions of tasks can have positive effects on retention then such things as the computer terminal for training in the control room could offer the opportunity for operators to test or rehearse their skill. An environment could be provided for practice in the use of knowledge in a variety of situations, and exploration of the knowledge base of the tasks over which the operators are expected to have control.

The overall conclusion of the review must be that a more detailed assessment of the situation is needed. It is hoped that it has provided some pointers as to where such assessment should begin and has some suggestions of training techniques for the situations that are likely to be encountered.

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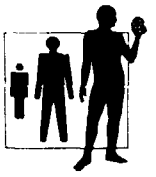

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