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TASK ANALYSIS AND TRAINING DESIGN.

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PERHAPS THE MAJOR PROBLEM IN TASK ANALYSIS FOR INDUSTRIAL TRAINING IS TO DETERMINE WHAT TO DESCRIBE AND ON WHAT LEVEL OF DETAIL. MANY DIFFERENT LEVELS OF DESCRIPTION MAY BE NEEDED TO ESTIMATE THE COST OF INADEQUATE PERFORMANCE TO A SYSTEM AND THE PROBABILITY OF ADEQUATE PERFORMANCE WITHOUT TRAINING--THE PROBLEM OF IDENTIFYING DIFFICULT COMPONENTS OF A JOB. IN THE ABSENCE OF DIRECT EMPIRICAL MEASURES OF THESE FACTORS, WORKING ESTIMATES CAN BE MADE BY APPEALING TO EXISTING METHODS AND CONCEPTS. SINCE SOME DIVISION OF TASKS INTO PERFORMANCE UNITS WILL BE NEEDED FOR VARIOUS PURPOSES, TRAINING TAXONOMIES ARE REQUIRED. ALTHOUGH TAXONOMIES SHOULD INCLUDE A HIERARCHY OF EXHAUSTIVE, MUTUALLY EXCLUSIVE CATEGORIES, EACH WITH A SPECIFIC TRAINING REQUIREMENT, THE RELATIVE POSITION OF SUCH CATEGORIES CAN BE EXPECTED TO VARY. IN RESPECT TO ACTUAL EVALUATION OF TRAINING TECHNIQUES, EVIDENCE ON SPECIFIC TRAINING CONDITIONS AND THEIR APPLICABILITY IS STILL FAR FROM COMPLETE. MOREOVER, TASK ANALYSIS MUST TAKE INTO ACCOUNT THE ENVIRONMENT AS WELL AS THE CONTENT OF TRAINING. (THE DOCUMENT INCLUDES 59 REFERENCES.) (LY)

TASK ANALYSIS AND TRAINING DESIGN

by

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One expression of the classical notion of instruction is that "theory" is first learned in some more or less formal setting and subsequently applied "in practice". In recent years this idea has been increasingly questioned - the experimental evidence being perhaps most convincing (or disturbing) in the field of electronics maintenance training. One experiment, for example, studied the abilities of maintenance men in terms of knowledge of theory, and a carefully constructed test of field fault finding performance on real equipment, (Williams and Whitemore, 1959). It was found that, whereas knowledge of theory was at its highest on leaving the training school, declining steadily thereafter, ability to find faults was poor initially but steadily improved with experience in the field. Now when it is said that one variable is dependent on another, or at least that the two are correlated, one is a little uneasy about the assertion when it turns out that they are not only independent, when measured, but tend to move in opposite directions over a period of time.

In view of this sort of finding, it has been argued that instruction should be task-oriented rather than based on a priori analyses of subject matter, (e.g. Wallis, 1966). Indeed, a relatively specific statement of the

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objectives of instruction, based on observation of task performance, has been suggested as the defining feature of training as opposed to education. Clearly a major advantage of having explicitly stated objectives in job performance terms is that instruction may be evaluated - i.e. the language of the statement will hopefully be operational enough to generate test situations, which in turn offer a measure of the extent to which job performance has been improved. Those familiar with the field of programmed learning will recognise the argument.

This unfortunately is easier said than done. The list of different prescriptions for task analysis is suspiciously long, suggesting that here is an area where methodological difficulties abound. At a time when powerful new training techniques are evolving, it is important that equally powerful methods for determining training requirements are developed.

Task Analysis - What to Describe ?

Need for a Rule

Perhaps the major problem, when one is confronted with the performance of an experienced man in a real situation, is what to describe and at what level of detail. To set out to make a complete description of performance on the grounds that this is bound to include the training information required, is to court disaster. Subsequently extracting the essential training information will be a major undertaking, if it proves possible, and a return to the job situation in search of more specific information will probably be necessary.

To meet this difficulty we have found the following rules useful. Performance is first described in gross terms and two questions are asked, namely (i) what is the probability without training of inadequate performance ? and (ii) what would be the costs to the system of inadequate performance ? If the best available estimates of these values, or rather if their product is unacceptable, then the performance in question is re-described in more detail, i.e. broken down into subordinate operations and each of these is then submitted in turn to the same decision rule. In some cases it will be necessary to re-describe several times in increasing detail, in others not. The analysis ceases, either when the values specified in the rule are acceptable to the system, or when training requirements for adequate performance are clear.

It follows that, for any single task, there may be many different levels of description, varying from relatively gross statements of procedure to micro-analyses at the sensorimotor process chart level. Any operation in this hierarchical description will, in common with most other descriptive schemes, have an input or cue, an output or response and response feed-back or knowledge of performance. However the extent to which input, output and feedback elements are identified and described is determined throughout the analysis, by application of the same decision rule, e.g. estimates are made of the probability, without training, that a cue will be received, a response adequately performed and the resultant cost to the system if they are not.

Cost of Inadequate Performance

We do not wish to minimise the difficulties in making the estimates required by the rule we have proposed. Clearly the more exact they are, the more sensitive will be the analysis. Nevertheless, some attempt to apply the rule, however crude the estimates, will be helpful in extracting the task information essential for training.

With regard to the cost factor, the cost-critical components of the task should be specified by the sponsor, i.e. it is not properly speaking the job of an analyst interested in training to make these evaluations. Which components are cost-critical should be deducable from overall system objectives - and if it turns out that these are, in the event, not sufficiently well defined, this may be a beneficial side-effect of the analysis. However, we would note that a useful guide to identifying performance which is critical because of the point in time and space at which it occurs, is the Operational Sequence Diagram described by Brooks (1960) and Kurke (1961). This diagram will help to isolate performance which lies in a "critical path", or on which many other operations depend etc. Whatever the approach to cost-criticality, the analyst should beware of a tendency to overlook the rare but costly emergency.

Cost-criticality aside, another criterion for arriving at an estimate of the cost of inadequate performance is the frequency of its occurrence. Here activity sampling is an obvious and most useful technique or set of techniques. These have received extensive treatment in texts written against a background of classical work-study (e.g. Barnes, 1958) and more recently in texts on engineering psychology (Morgan, Chapanis, Cook and Lund, 1963, Chapanis, 1959). These techniques are especially useful when describing jobs which embrace a wide variety of tasks, e.g. supervisors, salesmen, some office jobs. It is probably generally true that the smaller the organisation, the more varied will be the tasks which are the responsibility of a single job encumbent, and therefore the more appropriate will be the use of some activity sampling technique.

"Difficulty".

With regard to the other value in the rule, probability of adequate performance without training, this is recognised by many other writers as the general problem of identifying the difficult components of a job. Writers such as Folley (1964 a) and Demaree (1961) advocate explicit attempts to "rate" difficulty. In some industrial settings, of course, product quality or standards may be readily determined and, for training purposes, these may be a useful guide to task difficulty. The discrepancy between the time of a skilled worker and a novice has also been proposed as a useful indicator of the difficulty of the different stages of a task.

R. B. Miller contributes the important point that difficulty may arise, even when component tasks are in themselves easy enough, if they overlap in time and force the operator to time share his attention (Miller, 1962 a and b). Wherever this may occur it will probably be advisable to record cues and responses on a time-line as Miller prescribes (though again, we would emphasise a discriminate use of time-line recording : this, like other formats, if used indiscriminately throughout the description of a job, will be time consuming and generate an unwieldy record containing much unwanted detail). Another more obvious source of difficulty mentioned by

Miller is the presence of degrading or disruptive environmental conditions, which, again, may render an otherwise easy operation difficult.

In some instances difficulty may be a function of the cue alone or the response alone, rather than the whole task. With regard to cue difficulty, we would refer to Miller's notion of competing and distracting cues, and to Stolurow's (1964) ingenious formulation of cue difficulty in terms of the complement of (1) sufficient and (2) necessary cue components in an array. A cue may also be difficult simply because it is near the absolute or difference threshold. Finally, the more variant the sequence of cues (or the time intervals between them) the more difficult will be the task - to the extent that learning consists in utilising sequential dependency (Annett and Kay, 1956). A special case is the task where the operator's own performance, especially if he is a novice, can augment the variance in cue sequence and intervals.

With regard to response difficulty, a general rule which has been put forward, is to look for movements which are unusual or conflicting with well established "every-day" patterns (Miller 1962 a) - though in the latter case job re-design may sometimes be a more rational (and less expensive) expedient than training. In some speed skills the difficult components may only be isolated at therblig level where the notion of perceptually stringent elements (e.g. "position", "grasp") is a useful one (Crossman, 1956). Indeed some writers would propose that the perceptual load of the movement - i.e. difficulty - may be objectively scaled (Crossman 1956, Fitts 1954). In still other tasks, difficulty may lie not so much in the nature of the response as in the nature of the response feed-back. This is of course a special kind of cue and may be more or less difficult in the ways which any cue may. However, its temporal characteristics may be especially important, particularly in "continuous", or "tracking" tasks where, again, the extent of the lag may constitute an objective scale of difficulty, (though it is not, of course, the sole determinant of tracking difficulty).

Performance Classification and Training Design

Part-Task Training

In the absence, then, of direct empirical measurement of probability of inadequate performance without training and its cost to the system, working estimates may be made by appealing to existing methods and concepts like those we have just discussed. By repeated application of these criteria, the account of the task is confined to a specification of the terminal behaviour of a training course. However to specify the terminal behaviour is not to prescribe the course itself.

That the terminal behaviour must be approached through a set of component learning tasks is widely recognised. Some fragmentation into performance units manageable for the trainee will usually be necessary e.g. to prevent excessive errors, which will have to be unlearned, and to permit goal setting during the training course. To these arguments for part-task training has recently been added the further argument that performance should be classified into types or categories in order to identify appropriate training methods and conditions. Schemes for classifying performance, or "taxonomies" as they are sometimes, perhaps prematurely, called are by now very numerous.*

The 1953 papers by R. B. Miller were probably the first explicit attempt at a classification of behaviour for training. Miller has subsequently proposed several modifications of his now well known scheme for codifying the processes which intervene between environmental events and the responses of skilled men, e.g. scanning, search and detection of cues; identification of cues; short and long term retention of task information; interpretation, decision making and problem solving. Several of the classificatory schemes proposed by other writers are variations on this basic input - processing - output model.** However among the proposed categories are some which do not apparently refer to a process intervening between cue and response but which may rather be thought of as combinations of cue-response units, e.g. procedure or chain categories in which cue-response units are combined in a sequence; concept or generalisation categories in which cue-response units having the same response are combined.

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* Miller 1953 a, b and c, 1954 a and b, 1956 a, b and c, 1960, 1962 a and b, 1966, Bloom 1954, Cotterman 1959, Gagné and Bolles 1959, Jones and Fairman 1960, Lumsdaine 1960, Snyder 1960, Demaree 1961, Parker and Downs 1961, Stolurow 1961 and 1964, Willis 1961, Fitts 1962 and 1964, Gagné 1962, 1965 a and b, Gilbert 1962, Kidd 1962, Miller 1963, Folley 1964 a and b, Melton 1964, Underwood 1964, Wickens 1964, Crossman 1965, Folley and Chenzoff 1965, Mechner 1965.

** Cotterman 1959, Brooks 1960, Jones and Fairman 1960, Snyder 1960, Kurke 1961, Stolurow 1961 and 1964, Willis 1961, Fitts 1962 and 1964, Crossman 1965.

More recently there has been an increasing tendency to build analytic schemes with categories of this latter type, i.e. different combinations or configurations of cue-response units, notably by those interested in the analysis of material for programmed instruction (Gilbert 1962, Mechner 1965, Gagné 1965 a and b).

Criteria for a Taxonomy

As classification schemes become more numerous, it is proper to consider what criteria should be satisfied by a taxonomy of training. There are two main systematic criteria, namely that categories should be mutually exclusive and exhaustive. The major criterion, which is less easily met, is a set of categories, each of which has specific training requirements.

Cotterman (1959), Miller (1963), Stolurow (1964) and Gagné (1965 a and b), have all attempted to meet the criterion that categories should be mutually exclusive by careful formal definition. Gagné for instance defines his categories in language of this sort : "upon presentation of two or more potentially confusable stimuli (physically defined), make an equal number of different responses which differentially identify these stimuli, and no other responses" (multiple discrimination). However, two experienced workers in this field have reservations about this particular criterion : Miller (1966) considers that overlapping of categories is less important than the utility of the classification, and Crossman (1965) notes that his own terms "shade into one another, and difficult boundary cases arise but this is inevitable in any taxonomy".

The second systematic criterion, exhaustiveness of the list of categories, has been dealt with in two main ways. The approach of Cotterman (1959) and Stolurow (1964) has been to carry out massive surveys of the range of tasks in the learning and training research literature. Folley (1964 b) and E. E. Miller (1963), have adopted the other, less effortful, expedient of including a catch-all category defined to include any behaviour not otherwise classified. It seems to us that, for some time at least, any attempts at classification will, in the event, be subject to inevitable additions and re-formulations. Thus, the four categories of Gagné and Bolles (1959) have been increased by Gagne (1965 a and b) to six and more recently to eight.

With regard to the major criterion, i.e. a set of categories, each of which has specific training requirements, most schemes fail to meet this in any systematic way. Stolurow's (1964) taxonomy of learning tasks is an explicit attempt, although the dimensions which he found adequate for laboratory learning situations require further evaluation with real, occupational tasks. Gilbert (1962) is also quite explicit about the training conditions required for his three categories, but the cautious applied psychologist may well prefer to await empirical evaluation of some of these, e.g. the proposition that the units in a chain are best brought to mastery in retrogressive order. Probably the recent work of Gagné (1965 a and b) is the most systematic attempt to bring together, in a single scheme, the scattered evidence of category-specific training conditions. Furthermore, Gagne arranges his categories in a hierarchy, thus in addition to the specific conditions for each, there are specific pre-conditions, e.g. learning a routine or chain should be preceded by learning the necessary multiple discriminations, i.e. learning not to mix up the separate steps in the routine (1965 a). Similarly, learning a rule of the form "if a then b" should be preceded by learning the concepts a and b.

An important feature of Gagné's scheme is that sequencing of instruction is indicated by the hierarchical structure of tasks. It seems doubtful, however, that the performance categories will be observed in the same hierarchical order in every task, as Gagné assumes, e.g. that generalization and discrimination, (called by Gagné " class concepts") will always be found at a higher level in the structure of a task than chains. In an industrial task we have observed, the relative positions of these two categories in the task hierarchy was in fact the reverse of that in Gagné's scheme (1965 a and b). The task in question was a rather long chain, the starting up of a distillation column in a chemical plant. Most of the subordinate steps in the chain involved 'multiple discriminations' of plant nomenclature and locations, although many required the identification of "by-pass" and "isolating" valves, plant components whose appearance and position in the configuration of feed lines vary widely, but whose function is the same. Each thus constitutes a set of cues requiring the same response, i.e. by Gagné's definition, a class concept. A further point is the relative positions of the chain and multiple discriminations in the hierarchy of this task : these are consistent with Gagné's earlier (1965 a) account of his scheme but not with his subsequent (1965 b) revised scheme.

It seems, therefore, that to assume fixed superordinate and subordinate relations between a set of categories is perhaps to make unnecessary difficulties and certainly to restrict the usefulness of the hierarchical method of task analysis. A more defensible assumption might be that a task may always be analysed into a hierarchy of categories, but that the relative positions of the categories must be expected to vary.

Development of an Adequate Performance Classification

Because it has the potential value of indicating the sequencing of instruction, the analysis of a task into a hierarchy of performance categories is attractive. With regard to the categories themselves, however, much needs to be done by way of accumulating evidence on specific training conditions.

To illustrate the kind of information needed to establish worthwhile provisional categories, we may take some of the training indications which have been adduced for multiple discriminations. A basic problem in training this type of performance is making the cues distinctive. Three main ways of achieving this have been noted (Gagné, 1965 a, Gilbert, 1962) : (i) by prompts or additional cues, (ii) by using existing associations as mediators and (iii) by grouping potentially confusable pairs during training. To help the trainee distinguish the primary task cues, prompts or additional cues may be introduced and subsequently "faded" out. There is always a danger however, that they may become a crutch to performance. To the extent that supplementary cueing forces the trainee to attend to primary task cues, this danger may be avoided (Annett 1966). One way of ensuring the trainee does this may be to use some mixture of trials with and trials without the supplementary cues, (Angell and Lumsdaine 1961, Lumsdaine 1961). Sometimes existing associations may be used to mediate the cue-response links. Gilbert's (1962) application of this technique to the resistor colour code (one brown penny; five dollar bill is green) is well known, but more applications in practical training situations are desirable. Where the number of cue-response links is large, there are grounds for grouping together those with similar cues (Gagné 1950, Rotberg and Woolman 1963, Rotberg, 1964). On the other hand, Rothkopf's work on morse code learning suggests that this may not be an advantage for cues not amenable to verbalisation (Rothkopf, 1958).

Evaluation

A method of analysing tasks which reliably prescribes the training procedures required probably does not exist. One way of building up such a method may be to begin with a provisional set of categories for which there is some evidence, as in the case of multiple discriminations, of relatively specific training methods and conditions. (Such a set at the present time might include e.g. multiple discriminations, chains and generalizations). The next and essential step would be to test the value of providing specific methods and conditions in training the various components of real tasks. Another need is for experimental training courses to determine the value of the hierarchical ordering of categories. Two possible measures immediately suggest themselves. One would be the effect of ignoring or reversing the sequencing derived from the hierarchy. The other would be the extent to which overall mastery of a task depends on, or is facilitated by the location and correction of lack of mastery of subordinate operations made possible by a hierarchical analysis.

Training Strategy

Finally, the task analyst may have to resolve problems of how in Miller's phrase, "to encode capability" in the particular trainee population. It will often be apparent during task analysis that the same performance may be achieved in different ways. A most striking and well documented instance is the task of locating faults in electronic equipment. The repairman may, e.g. interpret symptoms and decide where to search on the basis of an amalgum of theoretical knowledge and experience, or he may consult a procedural guide which, for a particular symptom pattern, prescribes a search routine. However, the introduction of procedural guides may change the nature of the task from problem-solving to procedure following, indeed, in the drastic solution proposed by Shriver and his associates, the whole process of electronic repair down to component replacement is proceduralised (Shriver 1960, Shriver, Fink and Trexler 1964, Shriver and Trexler 1965).

For the earlier stages of task analysis we attempted to formulate decision rules for the analyst, i.e. the probability and cost of inadequate performance as a rule for what to describe, and subsequently we suggested demonstrable or testable statements about specific training conditions as a rule for which behaviour categories to appeal to. A similar rule is desirable for the rather general decision whether to teach principles or procedures embodying the principles. Here one must take account of several factors. Procedures are easier to train than principles and indeed may be supported by job aids and not need training at all. Less intelligent groups may achieve better performance by following procedures than attempting to work from first principles. On the other hand, the cost of producing good procedural guides may be high. Procedural training is by definition specific, does not transfer to other tasks, and may even interfere with learning other tasks; nor does it capitalise on any existing mastery of principles in previous tasks which _may_ transfer to the present one.

Other factors which must be considered are the conditions of the job situation, e.g. time-sharing of the task with other activities and environmental conditions which might disrupt or degrade performance. These factors might favour the choice of procedural training, as might other factors in the job situation such as cost and safety, since procedure following, if somewhat inflexible, is possibly more stable than performance depending on knowledge of principles. The existence of high labour turnover will obviously tend to make procedural trainir~ more economic : training in principles can be time-consuming and the training investment in an employee is correspondingly increased. It is perhaps significant that research into procedural training in the field of electronic maintenance has been much more extensive in the U.S. army, most of whose trainees are 3-year conscripts, than in the U.S. navy.

A consideration of factors such as these, i.e. of information not derived solely from study of the task itself, will be necessary for the implementation of any thorough-going task analysis. That is to say, if the analysis concerns itself not simply with the content of training but with the conditions and methods of training as well, it will recognise that factors such as the relative cost of performance aids and training devices, the abilities of the trainee population, transfer effects and labour turnover, may all affect the optimum design for a training course. In short, task analysis cannot be undertaken in isolation, but must take account, in common with other human factors technologies, of the constraints in the system where training is to be installed.

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