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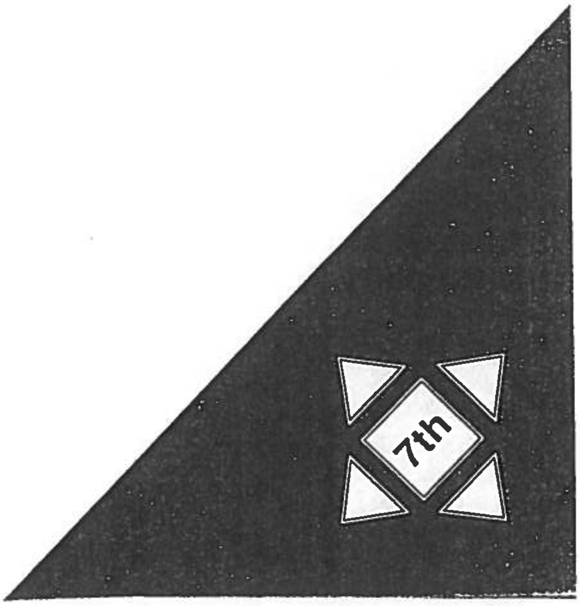

# Some Findings from the Learning of Assembly Work in Sweden

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## Abstract

This paper describes some changes of a fundamental nature which have taken place with regard to learning in assembly work in the engineering industry in Sweden where, in a number of cases, the research finding that a holistic view of the work itself can be of importance for learning has been noted and implemented. We direct attention to the factors which have proved to be of importance in the shift to efficient long cycle assembly work. The results are based on several years' experience of action-oriented research work within the Swedish motor vehicle industry.

## 1. INTRODUCTION

It is well known that the time required to complete a work task, e.g. to assemble an object, tends to decrease with the number of times the task has been performed previously. Learning functions that describe this effect may be specified in different ways.

It is often assumed that the required learning function has the form $y = an^{-b}$, where y is the time required for the n:th execution of the task, for some a, $b > 0$ (e.g., [1, 2]). This assumption implies, in particular, that the time needed for the 2n:th execution of the task is a constant fraction (specifically $2^{-b}$) of the time needed for the n:th execution. The parameter b, then, provides a measure of the rate of learning.

The above approach presupposes an indefinitely extended learning period and involves the assumption that the time needed to perform the task will continue to decrease forever and beyond any limits. These assumptions are clearly somewhat problematic. From a practical point of view, moreover, the salient question is often how long it will take for an operator to become "sufficiently skilled" at performing a task. The most significant measure of the rate of learning would then be the time needed to acquire such proficiency.

The rate of learning, however measured, is an important parameter to be taken into account when designing production systems. It has been suggested [3] that for short cycle work operators have to perform 2000 – 3000 work cycles before acquiring proficiency (i.e., before attaining a work pace of 110 MTM). If the work cycle is longer than 15 minutes approx. 300 - 400 repetitions are normally required [4, 5].

Earlier research has then aimed at finding generally valid relationships that describe learning times as a function of the work content (work cycle time). Data from [6] indicate however that the learning time length varies greatly between cases. Specifically, empirical evidence from the assembly of trucks and automobiles in Sweden indicates that for suitable objects, properly designed work tasks and favourable learning conditions, the number of work cycles required for acquiring proficiency can be reduced to a few hundred cycles or less.

Table 1. Relationship between cycle time, work pace and learning time for final assembly of some objects [6].

| Case | Cycle tim min. | Work speed MTM | Learning time weeks |
|---|---|---|---|
| 1 Truck | 45 | 115 | 2-4 |
| 2 Truck | 20 | 115 | 1-3 |
| 3 Bus | 120 | 115 | 4-8 |
| 4 Bus | 120 | 115 | 4-8 |
| 5 Automobile | 20 | 110 | 3-6 |
| 6 Automobile (kit) | 120 | 110 | 8-16 |
| 7 Diesel engine | 60 | 115 | 3-6 |
| 8 Diesel engine | 10 | 110 | 1-3 |
| 9 Vacuum cleaner | 11 | 110 | 1-3 |
| 10 Stove | 10 | 110 | 1-3 |
| 11 Stove | 12 | 110 | 1-3 |
| 12 Gear box | 40 | 110 | 1-3 |
| 13 Refrigerator | 11 | 110 | 1-3 |
| 14 Chain saw | 18 | 110 | 2-4 |
| 15 Gasoline engine (kit) | 62 | 112 | 1-3 |
| 16 Gasoline engine | 37 | 111 | 20-40 |

In order to be able to understand (a) why learning times fluctuate in this apparently inexplicable fashion and (b) why certain long cycle tasks demand fewer work cycles than short cycle tasks before the worker is fully proficient, it is necessary to distinguish between atomistic and holistic learning.

We will in the following discuss assembly work and deal with (a) the difference between these two types of learning, (b) factors which facilitate atomistic learning and learning in general and (c) factors which facilitate holistic learning and the shift from atomistic to holistic learning.

## 2. ATOMISTIC AND HOLISTIC LEARNING

Rogers [7] emphasized the importance of viewing learning as personal development. He considered that meaningful learning is only possible when the individual has confidence in his own learning ability and feels that learning will be personally rewarding and meaningful. Rogers' opinion that the individual's natural curiosity and inquisitiveness must control the teaching and learning processes greatly influenced the debate during the 1970's.

Researchers began then to turn their interest towards how the human mind treats, codes and stores information - how individuals build so-called cognitive structures. Learning then becomes a question of constructing meaning and it is emphasized just how important the difference between learning by heart and meaningful learning in fact is [8, 9].

Marton's research, based on studies of how students approach learning material, clearly shows that a distinction must be made between two forms of learning.

*Atomistic learning* can, for example, mean that the focus is primarily on the text of the learning material, in order to be able to reproduce the words of the text. This is related to an atomistic approach; the individual does not see the parts as having any clear interrelation.

In *holistic learning* , on the other hand, the individual focusses on the message or idea being communicated. Such an individual is said to have a holistic approach, i.e. he regards the learning material as a whole in which the parts are seen in relation to this whole.

Our experience from concrete processes of change in industry confirms that there is another kind of learning than that made use of in conventional series production and which has formed the basis for traditional learning curves. In addition to more efficient learning, there are qualitative differences in the work itself provided that the cycle time is long enough. But other conditions, to which we will return, must also be met.

Earlier discussions have presupposed atomistic learning of manual skills in individual assembly work, which has led to the conclusion that there exists a definable maximum cycle time with maintainable efficiency, for automobile assembly approx. 20 minutes. Later findings in connection with motor vehicle assembly in Sweden, however, indicates the potential for holistic learning, in which manual and intellectual skills are developed simultaneously and in which human pre-conditions, unexploited in traditional assembly work, are used to advantage, with emphasis on the rôle of the individual as member of a work group. Our most recent finding is that cycle times of two hours or more are certainly practicable in automobile assembly from a learning point of view - and economically advantageous.

## 3. PREVIOUSLY NOTED FACTORS AFFECTING LEARNING IN ASSEMBLY WORK

One obvious factor that affects learning time in assembly is *the number of components* to be assembled. The more components one assembles, the easier it is to forget one.

Note that fewer parts are assembled per time unit when assembling large objects with big components (e.g. trucks, buses) than when assembling small objects with small components (e.g. gearboxes, vacuum cleaners). As a consequence, it is often the case that fewer work cycles are needed to become proficient at assembling large objects than small objects [6].

This is because it is simpler to complete a large partly assembled object than to assemble something from small components. If there are a large proportion of concealed components, learning time is further increased. This is especially true if difficult fitting movements are involved. (The more the fiddling, the greater the number of repetitions required).

The *design of the object and its components* is also significant. Certain components have an obvious position, others not. Characteristics such as sequence dependency and asymmetry are positive from the point of view of learning.

Table 2. Number of components assembled per minute for some objects [10].

| Object | Components per minute |
|---|---|
| 1 Sailing yacht A | 0.03 |
| 2 Sailing yacht B | 0.04 |
| 3 Sailing yacht C | 0.13 |
| 4 Washing machine | 1.11 |
| 5 Truck | 1.21 |
| 6 Stove | 2.11 |
| 7 Rear door, automobile A | 2.32 |
| 8 Front door, automobile B | 2.37 |
| 9 Front assembly, automobile B | 2.37 |
| 10 Refrigerator | 2.79 |
| 11 Front door, automobile A | 2.89 |
| 12 Instrument panel, automobile B | 3.17 |
| 13 Rear door, automobile B | 3.39 |
| 14 Instrument panel, automobile A | 3.82 |

Other factors affecting learning in assembly work are [11]:

1 Prototypes which serve as models for real production. These can be looked at in cases of uncertainty. In order to be able to exploit a prototype it must be ensured that difficult aspects are not obstructed or obscured. However, this is often difficult to realize in practice, in, for example, short series or when large expensive components are involved. In certain cases buffers between work stations may be deliberately designed with a view to also functioning as work instructions.

2 Work instructions, e.g. files with work elements, photographs and the time for each element.

3 Exploded diagrams or visual representations of components can be displayed at each work station. The worker does not then have to leave his work and consult the work instructions in order to see how a certain component should be fitted.

4 Materials display. How materials are displayed is important in assembly work. To avoid any component being forgotten a palette or fixture is used in some instances. These hold exactly the required quantity of materials; when the palette or fixture is empty, the worker knows that he has fitted all the components.

| | |
|---|---|
| M | M |
| aM | Ma |
| raM | Mar |
| ryaM | Mary |
| rhyMa | Mary h |
| rahyaM | Mary ha |
| rahyaMd | Mary had |
| arahyaMd | Mary had a |

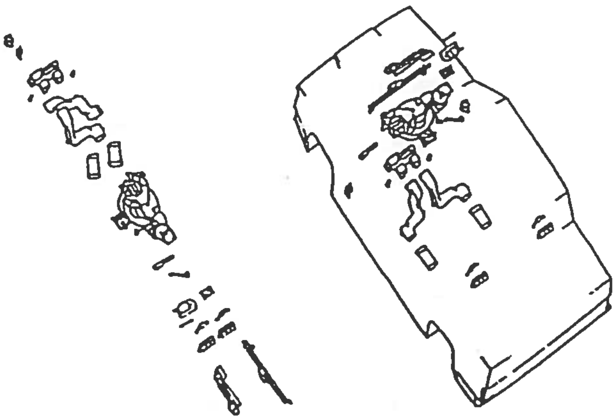

Figure 1. In traditional (atomistic) learning, learning time increases exponentially with cycle time, which is not the case in holistic learning. This is illustrated above in two examples; nonsense text compared with meaningful text, and automobile components arranged in assembly sequence as opposed to their final, assembled position in the completed automobile.

## 4. FACTORS WHICH FACILITATE HOLISTIC LEARNING AND THE SHIFT FROM ATOMISTIC TO HOLISTIC LEARNING

Learning can be speeded up considerably by taking advantage of the human capabilities of construction, recognition and successive activation of mental and motor patterns (cognitive structures as well as work patterns and rhythms)

Holistic learning is facilitated if the individual is provided with concepts to support his learning. This involves helping the individual to form wholes, e.g. "assemble complete luggage compartment", so that when the individual recognizes such a whole, the chain of work elements making up this whole is also recognized.

Work elements that constitute meaningful wholes are easier to learn than fragmented, meaningless tasks, so-called functional learning [12]. Nilsson also points out that learning must take place on real objects [13].

Earlier research has proved that long cycle time assembly work is efficient [12, 14, 15]. Efficient learning in this case requires [16], *first*, that the object to be assembled must have an intelligible structure - a requirement that is usually satisfied; automobiles and trucks certainly contain such generic characteristics [17]. *Secondly*, learning, as well as the work itself, is facilitated if the components are grouped and displayed in a manner that is congruent with the assembly work and the object to be assembled.*Thirdly*, interrelated verbal and visual representations of the work process, the object to be assembled, and the components to be fitted, should be used to guide and support the individuals' own conceptions.

These principles have been put into effect in the Volvo Car Corp. final assembly plant in Uddevalla, Sweden and have helped to drastically reduce learning times. In practice the new assembly concepts required radically new materials supply systems, assembly layouts, work instructions and variant specifications, all of which were supported by a completely new assembly oriented product structure.

The basis for the assembly work is this new assembly oriented product structure ("Assembly Geographical Atlas"). This structure constitutes a verbal and visual network both "inside the heads of the employees" and extending over the plant´s administrative systems.

The pre-conditions for vehicle assembly are special, since the possibility exists to exploit as work instructions both the components to be fitted and the objects being worked on by other individuals. In the final assembly of motor vehicles it is therefore possible to group the materials to facilitate assembly, kitting the materials for each individual object (team work on stationary objects).

In motor vehicle manufacture there exists a special pre-condition in that detailed information about the object is available from the design and central pre-production departments. This information, correctly exploited, can be utilized to build cognitive structures. Materials, work and work instructions support each other during the assembly work.

An example of this interaction, from Uddevalla, is that small components (clips, washers, etc) are kitted in small, transparent plastic bags where both the bag and its contents have meaningful designations. (These designations facilitate the learning of concepts and are related to the "Assembly Geographical Atlas").

This kitting shortens materials handling time and the bags themselves also function as work instructions. This is possible since the majority of components in an automobile are small, which permits the work itself to be described with a high degree of precision and surveyability. This would not have been the case if large components had been involved. These are fewer in number and their position in the object soon becomes obvious.

In Uddevalla the worker opens several bags at a time and places the components within reach. The status of the work can be deduced from observation of both the components and the object itself. (Deducing the status of the work from the object alone is not always easy since both worker and object often obscure components).

Knowing how far the work has progressed is especially important in team work, since assembly is in this case often interrupted by helping, or being helped or disturbed by, other workers.

In traditional materials supply the components would instead be displayed in boxes for picking, described only by means of part numbers, and merely stretching the hand over a rack of different boxes each containing the same component increases handling time, at the same time as the operator must memorize several series of part numbers.

## 5. CONCLUSIONS

Our extensive experience from research on and implementation of new assembly concepts in the Swedish motor vehicle industry has provided vital insights regarding the realization of sociotechnical principles, including work organization based on autonomous work groups. This experience has led us to question a strict application of traditional learning theory when designing assembly work.

Note that short work cycles and line assembly tend to generate fragmented, meaningless work tasks, so that short work cycles and traditional assembly concepts are in a sense an impediment to rather than a pre-condition for fast learning, contrary to the classical theory.

Material supply systems and product flow patterns, previously regarded as critical restrictions in efficient learning, as required in efficient long cycle time vehicle assembly, have resolved. Our recent findings indicate that it is the size of work teams and intra-team work patterns that are critical today. As Entwistle [18] points out, the learning process and the complex social context in which individual learning takes place are rather more important factors.

Chaffin [19] points out that the motivation of the individual to achieve proficiency quickly is an important factor in the learning process. It is our decided opinion that one of the most interesting research fields in industrial work in the future in order to further develop knowledge of learning will concern incentive structures and their interaction with work organisation and technology.

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