Human Computer Interaction within an Industrial Psychology Framework

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Dans l'interface homme/ordinateur, il y a deux controverses: contrôle de l'utilisateur contre contrôle du système, et approche moléculaire contre approche molaire. Cet article montre, dans le cadre de la psychologie industrielle que l'utilisateur doit être sous contrôle et que l'approche molaire est la plus utile. La force de la démonstration se nourrit de trois vecteurs de recherches: apprentissage, effets de stress et optimisation de l'interface. Elle appelle à réfléchir à une approche cognitive, étroite et technique qui pourrait conduire à des solutions impraticables, entraînant des conséquences négatives à long terme sur la performance et le bien-être.

There are two controversies, user control versus system control and a molecular versus a molar approach in human computer interaction. This paper argues within an industrial psychology framework that the user should be in control and that a molar approach is more useful. This line of argument is substantiated in three areas of research: training, stress effects, and optimisation of interaction. This calls into question a narrow cognitive engineering approach that may lead to impractical solutions that may have long-term negative consequences in performance and well-being.

INTRODUCTION

I would like to take sides in two controversies of the human–computer interaction literature: human control versus machine control and molecular versus molar approaches. From an industrial psychology point of view these two controversies are of prime importance in various problem areas of human–computer interaction: how to do training, how to deal with stressors and how to optimise systems. My argument will be that stress effects are reduced and performance increased when attention is given to them from a high-level molar approach and when user control over the system is high. This is particularly so when actual working conditions are

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the focus. The problem of much of the now-dominant cognitive engineering approach to human computer interaction is that it is oriented to low-level experiments and to increasing machine control. This is so because the issues are seen within a narrow experimental tradition and with a narrow focus that does not take into consideration the real work situation and potential long-term effects. I would like to argue against these tendencies. Thereby, this contribution should be viewed to be compensatory (and sometimes polemical) to the lack of emphasis on real workplace issues in cognitive science approaches to human–computer interaction.

At first sight, the two controversies mentioned seem unrelated. However, they often coexist. First, programmers tend to determine human–computer interaction. They often see the human as a dependent variable because they concentrate on the program. The program is better when the task gets done effectively; humans are often seen as imperfect penetrators that have the potential to disturb the functioning of the system. Thus, control is given to the machine and not to the human. At the same time, good programming necessitates concentration on details. Therefore, a low-level approach makes sense to the programmer. Second, concepts that emphasise a low-level approach also tend not to consider control over the system as an important issue (e.g. Card, Moran, & Newell, 1983). Similarly, concepts that discuss issues of human–computer interaction on a high level also tend to stress the importance of control.

I want to argue for a high-level approach and for human control over the machine. This is a theoretical article in which I would like to substantiate this view in the areas of training, stress at work, and optimising human–computer interaction by citing the relevant empirical studies in the literature. Before I can do this, it is necessary to discuss the concepts.

CONCEPTS

The Level of Approach Controversy

The level of approach controversy is curiously reminiscent of the debate on molar versus molecular learning theory between Hull and Tolman about 50 years ago. In the meantime learning theory has clearly moved away from Hull's doctrines to a more molecular viewpoint. In human–computer interaction the molecular approach argues for an analysis of action on the lowest level, combining this with precise operational measurement and mathematical laws. For example Card et al. (1983) and Newell and Card (1985) argue for this kind of approach, that "there is a small number of information-processing operators, that the user's behaviour is describable as a sequence of these, and that the time the user requires to act is the sum of the times of the individual operators" (Card et al., 1983, p. 139). They describe the human as consisting of long-term memory, working memory (consisting of visual image store and auditory image store), the perceptual processor, the cognitive processor and the motor processor. Each processor needs a certain amount of time, specified in milliseconds (msec); for example, the cognitive processor needs about 70 msec. So, for example, the time a person needs for pressing "yes" when two symbols are identical and "no" when they are not, is calculated to be 310 msec after the presentation of the second symbol: 1 perceptual processor for perceiving the second symbol (100 msec) + 1 cognitive processor for matching first and second symbol (70 msec) + 1 cognitive processor for deciding what to answer (70 msec) + 1 motor processor (70 msec). Their keystroke model is similarly elementaristic; it proposes, for example, that in order to evaluate a move on a word processor, the number of keystrokes should be counted (and when designing the system, minimised). Card et al.'s arguments for their approach seem to be threefold: (a) an approximate quantification is better than none; (b) only a hard science approach (providing quantitative laws) will be accepted by the system designers; and (c) this approach allows for an analysis of design alternatives *before* they are actually designed.

An alternative school of thought emphasises molar high-level approaches (Carroll, Note 1; Norman, Note 2). This is well exemplified in the volume edited by Norman and Draper (1986). Although it is a pluralistic book, the contributions are usually high-level ideas, metaphors (e.g. design in architecture and design of interfaces), and paradigms rather than detailed ready-to-use quantifiable low-level concepts. An example is Norman's (1986) chapter on cognitive engineering. He specifies an action theory framework consisting of goals, intentions, action specifications, execution, perception, interpretation, and evaluation. These high-level concepts (like intentions) cannot be measured in milliseconds. He goes on to contrast the designer's model with the user's model, emphasising the differences and the fact that the user cannot directly recognise the designer's model, but can only work via the system's image. Clearly, this approach lacks the rigour of Card et al., but it is more applicable to workplace issues because it allows the analysis of everyday life behaviour in work situations.

Control

The question of human control versus machine control is not yet an open controversy but it looms behind many issues (Boddy & Buchanan, 1982; Frese, 1987a). It is related to the question of which kind of division of functions between humans and machines should be aimed for. Personal control can be defined as having an impact on the conditions and on one's activities in correspondence with some higher order goal (Frese, 1987b). This implies that people are able to decide on their goals, their plans to reach the goal, the use of feedback, and the conditions under which they work. These decisions may refer to the sequence of how one does things, the timeframe (how quickly and when) and the content of the goals, plans, use of feedback, and conditions (Frese, 1987b). In other words, control implies that one is able to decide and that one is able to use the optimal, organised way to achieve one's goals.

There are several factors which can be conceptualised to be prerequisites of a sense of control although they are not identical with control: (1) *Functionality* refers to whether a computer program allows and enhances the completion of a task. One issue of functionality is, for example, whether the computer system models real world tasks. Thus, a statistics program should calculate correctly and do what it is supposed to do. (2) *Transparency* implies that users can develop an internal model of the system functions (Maass, 1983) and that they can develop the needed efficient skills. Thus, the system should not confuse the user by giving different commands to do the same thing under different modes or by giving explanations that are inconsistent or only half true. (3) *Predictability* has some overlap with the concept of transparency. If a system is not predictable, it is most likely not transparent. However, transparency refers to the present, predictability to the future. If a system's behaviour cannot be foreseen it is not predictable.

CONTROL AND LEVEL OF APPROACH IN TRAINING

Training is done, of course, to develop the skills to use the control possibilities that the environment offers. The meaning of the two issues, control and level of approach for training, are described in Table 1. The first dimension (training process) distinguishes sequential from holistic training. In a sequential training, the action is partitioned into small low-level sequences that are taught and practised separately. Many computer-aided tutorials follow this kind of program, presenting a step and then asking the person to perform the respective action (Greif, 1986). The holistic training program, on the other hand, furthers an integrated mental model, in which high-level explanations are used, and where understanding of the whole system is emphasised.

The second dimension differentiates passive versus active training strategies in developing a mental model of the system. In the active approach, the trainees have control over what kind of a mental model they develop and they can actively try out its adequacy. In the passive approach, the trainees have no influence on what model they develop but they have

TABLE 1
A Descriptive Taxonomy of Training Methods

Training Process	*Development of Mental Model* *Passive*	*Active*
Sequential	X	
Holistic		X

to learn the one that is given to them (actually, of course, the user will always insist on some level of control over the development of their mental models).

In an experiment, two methods were compared that are most different from each other—the low-level and passive training and the high-level program with control (details in Frese et al., 1988). The latter shows advantages on a number of performance variables (an example is corrected error times in Fig. 1). This means that a training program that combines a high-level approach with higher control gives better training results.

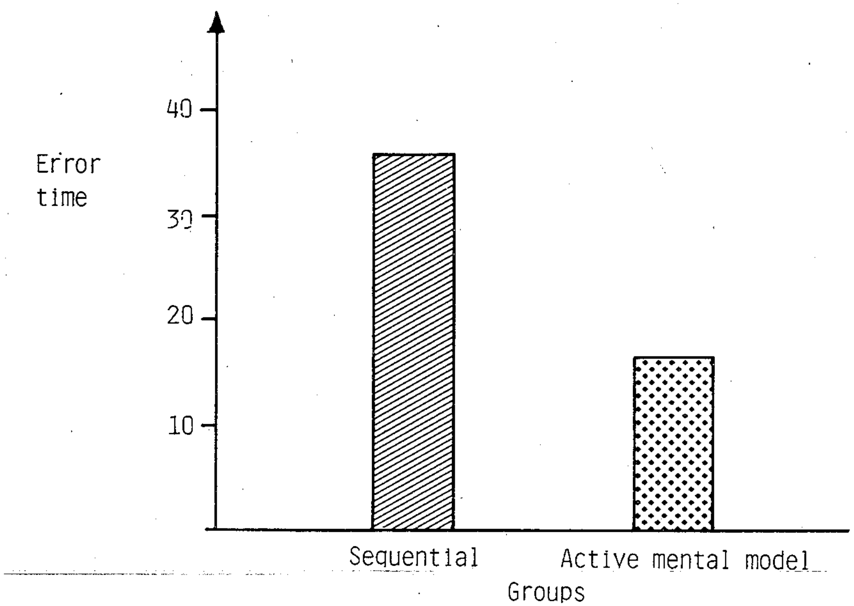

FIG. 1 Comparison of a sequential training group (sequential and passive) and an active training group (active and holistic).

CONTROL AND LEVEL OF APPROACH IN STRESS RESEARCH

Level of Approach

The problems of the molecular approach (as against the molar approach) can be exemplified in research on stress, for example in the area of eye pain. There is evidence that VDT (visual display terminal) work is physiologically somewhat demanding on the eye (Haider, Kundi, & Weissenböck, 1980; Smith, 1984; Stark & Johnston, 1984; Wilkins, 1985). But this does not necessarily imply that eye *pain* is developed as well. There has been a large array of studies that simply measured the time spent in front of the VDT and correlated this with eye pain. These studies can serve as examples for a simple, mechanistic, and low-level approach because the psychophysical unity of the person is not considered. No wonder that these studies did not lead to clear-cut results. Some found correlations (e.g. Gunnarson, 1984), some did not (Hartmann & Zwahlen, 1985; Howarth & Istance, 1985). Because work at the VDT had been studied in isolation, the decisive parameters of the work situation have been left out—the work content and the work situation in general.

Eye pain is a reaction to the workplace as a whole, that is not only to working with a VDT but to other stressors and to the work content as well. The overall stress situation leads to psychosomatic complaints. Eye pain may be a part of psychosomatic complaints and the eyes, as they are used heavily when working with the VDT, may be the part of the psychophysical unit that is affected most easily. But there is no direct relationship between using a VDT and eye pain (except, of course, if the VDT does not conform to basic hardware ergonomics).

In Figure 2 our conceptualisation of the stress process is described: the psychosomatic reaction tends to appear in that organ that is most strongly in demand in a physiological sense. In the case of VDT work, this may lead to an increase in eye tension. However, of equal importance is psychological stress at work. Psychological stress may not only increase eye tension but also eye pain. When there are high background psychological stressors, higher muscular tension ensues as a general physiological response. This may also affect eye fatigue. High background stress additionally leads to a stronger pain sensation. So most often only the combination of both, the physiological "overuse" and the psychological background stress, leads to eye pain.

This reasoning allows the interpretation of the finding that there is an association of eye pain with time spent on a VDT on "bad" jobs (like data entry typists, who have high stressors and little control) but not in "good" jobs (like programmers or secretaries with a wide range of tasks) (Cakir, 1981; Coe et al., 1980; Dainoff, Happ, & Crane, 1981; Läubli, Hünting, & Grandjean, 1980; Smith, 1984; Smith, Cohen, Stammerjohn, & Happ, 1981). Only with this more high-level approach is it possible to integrate the various findings into a coherent picture. The more low-level, mechanistic approach of just looking at the time a worker spends looking at the VDT invariably leads to inconclusive or wrong results.

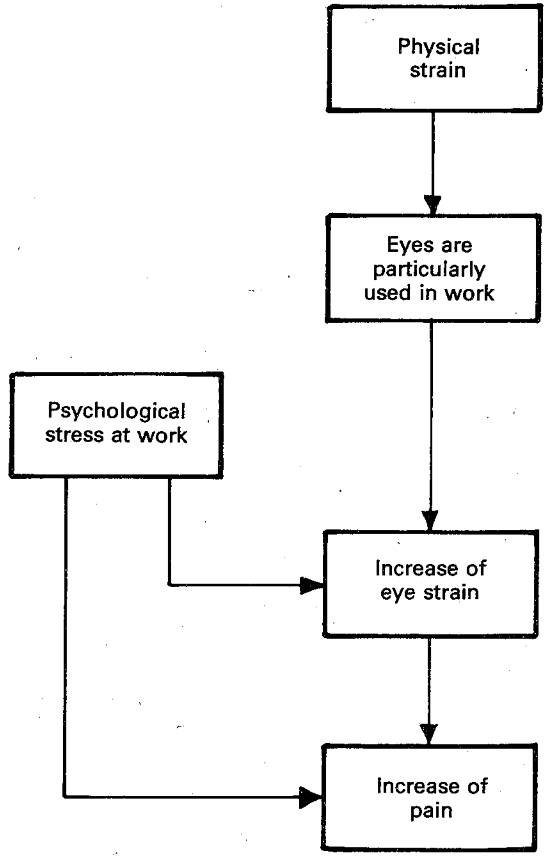

FIG. 2 Development of eye pain in the context of work.

Control and Stress

The issue of control helps to answer the question of what constitutes a "good" and a "bad" job as well. Control at work implies that people are able to change environmental conditions and influence their own activities (a more detailed discussion of the issues of control and stress is found in

Frese, in press). Control has been shown to be related to stress effects directly and as a moderator. In one group of studies, people who had little control at work showed more signs of psychological and psychosomatic dysfunctioning, e.g. depression, psychosomatic complaints, irritation/strain, exhaustion, anxiety, consumption of pills, sick days, and low self-esteem (Caplan et al., 1975; Dunckel, 1985; Frese, Saupe, & Semmer, 1981; Gardell, 1971; Karasek, 1979; Kohn & Schooler, 1982; Kornhauser, 1965). This is also true of studies of office workers with computerised office equipment (Cakir, 1981; Schardt & Knepel, 1981; Smith et al., 1981; Turner & Karasek, 1984). A second group of studies showed that control had a moderator effect: stress had a higher impact on psychosomatic complaints (Semmer, 1982) and on death from heart attack (Karasek et al., 1981) when control was low and a low impact when control was high.

One implication of this is that the strategy of stress reduction may be more unrealistic than a strategy of control induction. In general, the following reasons speak for this thought:

1. When a person has control, he or she is able to influence the stressors directly. Thus, those stressors that are particularly bothersome can be abolished by the person him- or herself.
2. Control has a moderating function, that is under low control, there is a high impact of stress on psychosomatic and psychological dysfunctioning whereas there is a low impact under high control conditions. This is also in accord with much of the experimental literature on stress (e.g. Glass & Singer, 1972; Seligman, 1975).
3. The issue of control is even more important when dealing with new technologies. Technological innovations change workplaces very quickly. Doing research on the question of which stressors need to be changed takes a long time. Thus, the respective workplace will already be changed again, before stress research has the chance to lead to a reduction in the respective stressors. An alternative strategy is to give workers control over stressors so that those stressors that the workers perceive to be most problematic are reduced.
4. As there are certain inter-individual differences in what conditions are perceived to be stressors and because a workplace can only be geared to the individual when there is a high degree of control at work, it is much more useful to increase the individuals control over stressors than to do away with stressors themselves.

In summary, in scientific thinking about stress at work related to new technology, it is more productive to use high-level approaches. Additionally, scientific and pragmatic reasons speak for increasing control at work rather than directing one's efforts just to decreasing the stressors.

CONTROL AND LEVEL OF APPROACH IN OPTIMISING SYSTEMS

There are many areas in which our two issues of level of approach and control play a role. It is not possible to discuss all of them here; only two were selected: (1) keystroke model versus management of trouble, and (2) direct manipulation.

Keystroke Model versus Management of Trouble

The Card et al. keystroke model (1983) conceptualises an optimal system to have a low number of keystrokes, to be simple to learn, to prescribe one best way, and to be foolproof. This is in line with their esteem for Gilbreth (1919) who completed Taylor's (1911) work. There are many lines of criticism directed towards their approach: they may have a wrong conception of the design process, because the design process does not conform to their top-down idea (a general conception, e.g. a task description or a general law of psychology first, and then delineating the steps from it) (Carroll & Rosson, 1984); their approach may be empirically wrong even on the micro-level (Greif & Gediga, 1987); their emphasis is one-sided because the shortest possible command string may ignore issues of comprehensibility and memorability (Shneiderman, 1984); their approach is not exact but pseudo-exact and incomplete because they leave out so many issues (like errors) (Greif & Gediga, 1987; Shneiderman, 1984); the most important issue is, however, that it does not take into consideration the real world of work and is therefore naive, impractical, and emphasises wrong issues.

One might argue in defence of the low-level model that much work is not of the high-level creative and intellectual type but consists of low-level and routinised activities. However, the Card et al. formulation is not better applicable to routinised activities as routines do not require those decisions that are implied by the model (e.g. the comparison of two alternatives does not have to be done any more when the activity is routinised). Moreover, all the issues discussed above are important for routinised as well as intellectual tasks.

This does not imply, of course, that their approach does not have any empirical validity in a small set of problem areas. For example, the keystroke level analysis is clearly adequate for designing a keyboard. However, when it comes to work situations, their one-sided approach may become a hindrance to the development of a design of human–computer interaction that helps to do the tasks at work (the task, by the way, lies outside the computer—note that this is a different and more high-level conception of task than the one used by Card et al., 1983).

An alternative approach that is much more adequate is suggested by Brown and Newman (1985): management of trouble. This implies that a computer system is optimal when it allows easy repairs and changes. No "one best way" is to be achieved, as there is not *one* best way but many (Greif & Gediga, 1987) and the goal is not to do away with errors but to give optimal conditions for dealing with errors and for repair when an error has appeared. This makes something like an UNDO command a central concept within this type of approach (for details and a theoretical discussion of the role of errors, cf. Frese & Peters, 1988 and Frese & Altmann, in press).

The repair concept is more useful at the workplace for four reasons:

1. It is impossible to predict all the design problems. Therefore it is wrong to try to anticipate everything and develop a maximal design (as the keystroke model implies). Rather the system should allow and give tools to fix up-coming difficulties.
2. Because work tasks are very different (and usually cannot be anticipated in detail) and as there are many adaptation problems when using systems for specific tasks, the flexibility to adapt is of utmost importance (Gasser, 1986).
3. Individual preferences cannot be planned and should not be abolished (as in the concept of a one best way) but rather nourished and supported (Ackermann & Ulich, 1987).
4. Control also has a general effect on performance. If one is repeatedly in situations of non-control, passivity increases and an active, planful and goal-oriented approach is reduced. Non-control implies that one does not have to develop one's own goals and plans of action. Being able to repair means to have control.

Quite clearly, the concept of management of trouble is a high-level approach and it works with molar tools and instruments. Additionally, it also implies more *control*. Management of trouble gives the human being control because *the user* has to manage the trouble. From the very start, one does not try to develop a maximal system. The keystroke model, on the other hand, puts as much control as possible into the system because it presupposes that there is one best way that is the result of scientific research and that needs to be prescribed to the user.

Direct Manipulation

The concept of direct manipulation has stirred up quite some excitement since Shneiderman (1982, 1983) coined the term. Direct manipulation refers to a system which continuously represents the object of interest, in which a complex syntax is replaced by physical action, and which immediately visualises the impact of the incremental operations (the principle of "what you see is what you get"). The Macintosh programs are examples (albeit non-optimal ones) of direct manipulation (Altmann, 1987). A good example is given by Hutchins, Hollan, and Norman (1986): when a graphic shows that there are two distinct subgroups in a datapool, one subgroup is circled and it as well as the respective statistics (e.g. the correlations for each subgroup) become visible in a second window.

Thus, communication is not done via symbols any more but via a direct change of "objects"; in the case of statistics direct manipulation fosters a different approach, e.g. an inductive understanding of data and the use of exploratory strategies. Of course, what is direct in a manipulation depends on the tasks to be done. The concept of direct manipulation is exciting because the potential of the computer is used, and because the analogy of programming language has been done away with and its advantages over a longer learning period have been empirically shown (Altmann, 1987; Frese, Schulte-Göcking, & Altmann, 1987).

In contrast, the keystroke model is closely bound up with the traditional programming concept and only makes sense within such an approach. It is not even possible to discuss the advantages or disadvantages of direct manipulation within the keystroke level model because the usefulness of metaphors for developing a mental model cannot be ascertained via low-level concepts.

The question is now, in how far direct manipulation is related to the level of approach and to control. One answer can be reached from Hutchins et al.'s (1986) discussion. They use two dimensions to describe direct manipulation: distance and engagement. The dimension "distance" refers to the distance between the person and the object and it relates to our notion of molecular versus molar approaches. In command language (a notion with a high distance) a plan has to be decomposed into subplans, operations, suboperations, i.e. into smaller and smaller units until one can work with the computer. A high-level language (like direct manipulation), on the other hand, allows one to work on the same level as the psychological constructs, i.e. intention, goals, tasks, concepts one has about work, etc.

The second dimension "engagement" is related to the immediacy of feedback and to the potential for controlling the object and the task. Immediacy is connected to transparency and therefore it is related to control again: one can add something and take it back again, and one sees object changes immediately and directly. Although engagement is not the same as control, it is strongly related to it because it refers to how I can achieve my goal in an efficient way.

Within an action theory approach (Frese & Sabini, 1985), direct manipulation means:

1. The decision points are clearly discernible—this is the issue of transparency.
2. The result of a decision is immediately clear and can be revoked again—this is the issue of control.
3. Coming to terms with the object of interest is immediate and direct, it is not mediated by symbolic processes that have nothing to do with the task—again the issue of control.
4. There is a direct route to the goal, detours are not necessary—thus control is achieved.
5. The object of interest is manipulated within a molar framework that corresponds to people's thinking about the task.

Thus, again the two issues, control and level of approach, have been important, with higher control and higher level of approach leading to better and more useful results.

CONCLUSION

I have argued for a molar approach and user control over the system. These two controversies are related to each other and they are clearly relevant for the field of human-computer interaction, as the discussion in the areas of training, stress, and optimisation of systems shows. Of course, I do not argue that these two controversies are the only important ones, but they seem to be important enough to warrant more attention.

The emphasis on control is not new to the field of software psychology (DIN-Norm, 1988; Shneiderman, 1980; Turner & Karasek, 1984). However, it does escape the attention of some human computer researchers who do not take stress effects, training needs, and the real job situation into consideration. There is a long tradition in the field of industrial psychology of enhancing control at the workplace (e.g. Emery & Thorsrud, 1976) that stands in opposition to Tayloristic notions of job design. This discussion is too little noticed in the field of cognitive ergonomics.

The Card et al. formulas could lead to workplace designs within this Tayloristic tradition. This implies that there is one best way described by the machine to be followed by the workers (in spite of the fact that there is no one best way to be shown empirically). Furthermore, division of labour is emphasised because this makes it easier to prescribe in detail what has to be done by the workers. It is not necessary to describe the negative effects of such a job as this has been done elsewhere (e.g. Hacker, 1986; and two recent complementary critiques of Taylorism in human–computer interaction have been given by Hacker, 1987; Landy, Rastegary, & Motowidlo, 1987). Tayloristic job design leads to stressful jobs with little control and a high degree of dullness, to a stifling of the development of the person and to a reduction of human capabilities.

Similarly, there is ongoing discussion on the level-of-approach controversy (e.g. Carroll, Note 1; Newell & Card, 1985; Norman, Note 2). The argument has been here that a low-level approach is misleading if it is not integrated into a high-level approach because the real workplace issues are of a high-level nature. Because pure low-level approaches are naive and agnostic to high-level issues, computer systems and job designs are developed that lead to more stressful jobs and to lower productivity. It is suggested that research in the real work situation should be performed more often and a narrow "cognitive science" point of view be given up.

At the workplace, a user of a system has to work on a certain task—most often a task that is not known in detail to the programmer of the system. Users think of their tasks and their needs in high-level terms and expect to operate on these terms (otherwise the system becomes a problem that has to be dealt with first, before solving the task at hand). The user needs to adapt the system to his or her needs. There is a also a certain element of chaos at the workplace, that should not be streamlined into "one best way" procedures because most often performance is then reduced and creative and interesting solutions are eliminated. Furthermore, the workers develop metaphors and ideas of how to proceed. There are stressors at the workplace, that interfere with working on the task and pose their own problems.

All of these job conditions may have long-term influences on the person in terms of occupational socialisation (Frese, 1984). To encompass these long-range influences, industrial psychologists have suggested criteria of good work design, like protection against health damage and long-term reduction of well-being, provision for social interaction, and chances for the development of personality (Hacker, 1986; Ulich, 1980). A high-level approach and control for the worker will help deal with this complex situation better than a chimera of quantitative laws within a framework not applicable to the workplace.

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