The Development of an Experience-based Documentation System for Maintenance Workers in Germany

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Abstract:

This paper is one of a pair describing attempts to devise strategies for the effective implementation of continuing professional development for work-oriented communities of practice in Europe. The paper will outline the development of DIADOSYS: an experience-based documentation system for maintenance workers in Germany. The German discussion about experience-guided work has led to the question of how work experience can be used within the process of designing decision-support systems for skilled maintenance work. Some considerations about the nature of experience and about the problems skilled workers have in acquiring work competences within computer aided production environments are introduced in order to illustrate the design philosophy of DIADOSYS: a decision-support-system which stimulates workplace learning by enabling previous and present users of the system, including maintenance staff and shop floor workers, to exchange and build on experience.

The system is designed so the users from the shop floor themselves can fill in the information which is needed at work. One reason for the implementation of information systems on the shop floor is the high innovation rate and the rapid change in machinery and technical components within factories. Information about technology being stored in shop floor information systems has to be constantly kept up to date. Therefore shop floor personnel should have the opportunity to develop the "knowledge base" of an information system. This means opening up the design process for the shop floor workers, not only in relation to the user interface but also in terms of the functionality of the system.

Introductory discussion about experience-guided work

Before describing the experience-based documentation system itself, it is worth putting the development into the context of discussions about experience-guided work and how work experience can be used within the process of designing decision-support systems for skilled maintenance work. Until recently German discussions on changes in skilled work were influenced by the presumption of work becoming increasingly abstract, and the importance of theory-guided "systematically-preconsidering" behaviour at work [14]. The traditional, experience-oriented learning and practice originating from the handicraft trades seemed in an irreversible decline. However, "experience" is witnessing a renaissance [4; 16] and has been influential in "shaping work and technology" [7]. Discussion of 'experience' is relevant here to show the relation between experience and the design philosophy for the DIADOSYS experience-based documentation system for maintenance workers.

To command experience is a matter of the past reaching into the present. Aristotle pointed out: ".. many memories of the same object generate the capacity of an experience.." [2]. He also suggests that experience emanates from the sensory perception imparted by memory. In the process of developing experience, concepts of past events are remembered and modified. While 'experience making' therefore a person is simultaneously aware of the object he/she is experiencing and of her/his knowledge of this object. The process of experience-making (i.e. a new experience on the quality of the object of experience) presupposes a discrepancy between the object as currently experienced and its previous image, and leads to a process of revision or amendment with the end result that the individual has experienced a new facet of the object.

The dialectic term of experience introduced here, which implies experience-making as an act of reception (reception of the object) and at the same time as an act of production (production of the enriched images of an object), was first articulated by Hegel: "this dialectic movement that consciousness is performing on itself, not only on its knowledge but also on its object, insofar the new true object emanates thereof, is in principle what is called experience." [13].

It seems as if there are empirical proofs for Hegel's outline of his concept. Rubinstein, for example, reports: "experienced grinders are able to distinguish spaces of one to two thousandth of a millimetre of width with the naked eye, whereas human beings are usually only able to distinguish spaces of one hundredth of a millimetre. Steel founders can perceive even the finest shades of the light brown colour which are indicators for the founding temperatures. Workers in pottery and china industries who have to determine the quality of their products according to their sound, develop a sensitive 'technical ear'." [21].

It is neither the somewhat naive, immediate sensory perception which is producing such a performance, nor is it a subject developing concepts independently from the objective world. Sensory perception enriched by experience stands above "inexperienced" perception [18] and shows experience as both reception of the objective and production of enriched concepts of the object. When experiencing the world, the formative process of experience simultaneously absorbs views and ideas, thoughts and emotions. Experience is the sensory personal experiencing of an objective reality, but it is experiencing imparted by mental processes. Aebli [1] and Schön [22; 23] have developed their own approaches to the dialectic relationship between experiencing and acting and reflection and learning.

Concepts, which are recalled and modified during the experience-making process, can be visual images, although the production of experiences can also take verbal forms: concepts are often linked to names and terms. Experiences are thus remembered in various forms, from sensory attributes of the objective reality to linguistically coded work rules. In general the criterion of immediate usefulness for practical action influences the form of coding experiences. For example, experience on the adequate functioning of a machine clutch involves the recall of a sensory impression rather than a verbal description. Experiences though are also recorded in verbal forms, especially when they are integrated into general concepts. "Metals are electrical conductors!" is a mixture of experience and "book learning" for the majority of the maintenance workers [10]. Such a sentence is important for the practical activities of maintenance personnel, and it is coded as a sentence, and not as a memory of a metal which had the property of an electrical conductor. Nobody wishes or needs to experience this property over and over again.

The relation between experience and practical action/activity can be seen to have two dimensions. Firstly experiences are accumulated during practical doing, because the subject is interested in the conditions and prerequisites of his or her actions, in the actions themselves and finally in the consequences of the actions. The subject draws his or her attention to the actions, gets physically-sensuously involved, mentally duplicates the sequence of actions and memorises it. Secondly experiences are sought after during practical doing because the subject ignores or just partially knows the prerequisites or the consequences of his or her acting and wants to learn them. This moment of experience is especially emphasised in the surveys by Böhle et al. [4; 5].

There is a temptation to regard the accumulation of experiences as a by-product of practical action, but that this is not so is evident from those cases where subjects have accumulated little experience in spite of practical doing. Indeed the accumulating of experiences presupposes that the subject wants to learn about something, wants to make it his or her concern and wants to make practical use of it. Experience does not encompass a disaggregated mix of sensory perceptions. The content of experience is dependent on the context for one's own actions. At work experience is an important element of work process knowledge. It encompasses the contents important for one's own actions in a form that makes it immediately useful for acting, and Hacker points to the opportunistic character of expert knowledge [12].

Experts try out different actions they deem appropriate for the solution of a practical problem. For masters, this exploration is deductive, as in a derivation from systematic knowledge, and inductive from exploring and interpreting the situation. Such an intertwining of approaches can seem to an outsider to be "jumping" between different ways of problem solving. Empirical investigations made evident that the relationship between "know how" and "know that" is in some way more "dialogical" [25] than Dreyfus and Dreyfus [8] have assumed, when they proposed that experts utilise only memory of previous work tasks when carrying out a task. Expert knowledge was therefore seen as a matter of know-how which had become divorced from know-that and know-why. Experts, however, may fail to remember how they have carried out a specific work task as they try to establish a connection between know how, know that and know why.

Experiences (maintenance workers call them 'experience-values') can be passed on. Thus experience has, apart from individual and social qualities (based on the social character of icons and terms), also a collective or group-specific quality. Experience-based knowledge of corporate maintenance procedures are preserved and passed on [10]. Experience-values are often hard to explain, even with their embedding into the practical feeling of the maintenance worker, as the development of experience-values are not necessarily dependent on the individual performance of a single skilled worker, so that this worker would not necessarily be able to remember the specific knowledge that created this experience value. Experience-values are at least partially collective knowledge within maintenance processes. They are passed on with hints such as: "do you see ..., do you realise ... , do you feel ..., do you hear ... that ...".

Thus assessment of the objective meaning of a phenomenon is not transmitted as a theory (though it might contain theoretical insight), but is immediately absorbed by the field of sensory perception of the person in action. These conditions form the basis for communication between skilled maintenance workers. There is a common stock of experience values relevant for their work. Most of the time the mere hint towards an experience-value is sufficient - explanations are usually neither required nor could they be simply given. Much research has recently been undertaken around the topic of "implicit knowledge" [3; 17; 19; 20]. A concise overview is given by Boreham [6], who supports the assumption of a dual cognitive architecture and examines how the relations between implicit and explicit processes of thinking are reflected in different (from unconsciously to consciously controlled) thought patterns. This view defines experience as a comprehensive category which contains both explicit and implicit thinking.

Development of an experience-based documentation system for maintenance workers

Increasing importance is being attached to skilled industrial maintenance in computer-aided production, yet despite increasing planning and preventive maintenance, fire-fighting assignments, involving elimination of acute malfunctions, still represent a significant role for skilled maintenance staff. This means working under considerable time pressure and frequently their work situation is determined by machines and systems out of their range of normal functioning. The competence of maintenance workers in coping with such situations is characterised by experience-based action within a "community of practice" [15]. The diagnostic process itself is as far as possible experience-guided: skilled workers search for certain sensory related values which often lead them - as they know from experience - to the cause of the malfunction very quickly and without much effort [10].

Experience-based behaviour at work, however, is made difficult under the conditions of computer-integrated production, due to the opaqueness of technical phenomena and processes; the rapid rate of innovation in machinery and software; the convergence of originally separate metal, electrical and information-related processes; and the networking of formerly separate areas of production. The major problem in this situation is that technical documentation for equipment and machines is either not available or is inadequate. Work experience in troubleshooting and elimination of faults is usually not documented at all.

In developing work oriented solutions one has to keep in mind that every technical artifact necessarily contains an abstraction from work experience. A useful technical solution is complementary to rather than just a copy of human abilities (e.g. the use of wheels). Therefore although an abstraction from work experience has proved to be necessary within useful technical solutions it does not justify ignoring the experience of end users in systems design.

In order to support skilled workers' competences we suggest the development of an experience-based documentation system, as an alternative to the implementation of expert systems, which are often not complementary to the user's competences [10; 11]. The design of an experience-based documentation system for maintenance work which leaves the decision-making process to the user, includes the following objectives:

- the main objective is to provide adequate structures for supporting decision making by the shop floor personnel. Such a structure can, in principle, be viewed as a shell, in which maintenance-related knowledge can be input and used by the users themselves;
- The system contains a facility for inputting cause-and-effect interrelations to describe malfunctions which occur. Thus work experiences have to be translated into a cause-and-effect-chain which give, in a certain (practical and not necessarily scientific) sense, an explanation for the malfunction. The only information that shall be documented shall be that that has been shown to be relevant for the diagnosis of malfunctions which have actually occurred. In the course of time these examples accumulate and can be used for troubleshooting.

The system itself must be easy to use (for reasons of time pressure and as shop-floor workers are the main users). This means that the functions for the development and modification of documentation and diagnosis structures are extensively automated in order to minimise the operations necessary for operation of the system. Conclusions and decisions themselves, on the other hand, are not automatically made available since the competence of the users is based on their ability and responsibility to make appropriate decisions. One reason for this is that, while coping with contradictions; a mere hint (instead of an automatic conclusion) is often a sufficient support.

As shown in figure 1 a malfunction is presented within DIADOSYS as a structure of chains which lead from the phenomenon ("tool exchanger stops") to the final reason for the fault (e.g. "screws are loose"). This case actually happened and the documentation of the case, which was undertaken by the maintenance worker himself, can be read as follows: the tool-exchanger stops because the tool magazine stops, the tool magazine stops because the cog belt sprung over, the cog belt sprung over because the cog belt is loose, the cog belt is loose because the screws are loose. Another case that has happened leads from the same phenomenon to the final reason "too little oil". The explanation of these malfunctions lies in the chain links between the phenomenon and the basic reason - nobody would understand the reason for the malfunction if only the final cause - "screws are loose" - had been quoted, but it is easy to understand if the chain links in-between are taken into consideration. As those chains often extend over the space of one page on the monitor, a number of functions are offered (overview, go-to etc.) to navigate through the system very quickly. Relatively little information has to be entered, because of the nature of the experience of the users and their ability to recognise and identify the difference between an actual situation and the computer data and to draw conclusions from the comparison.

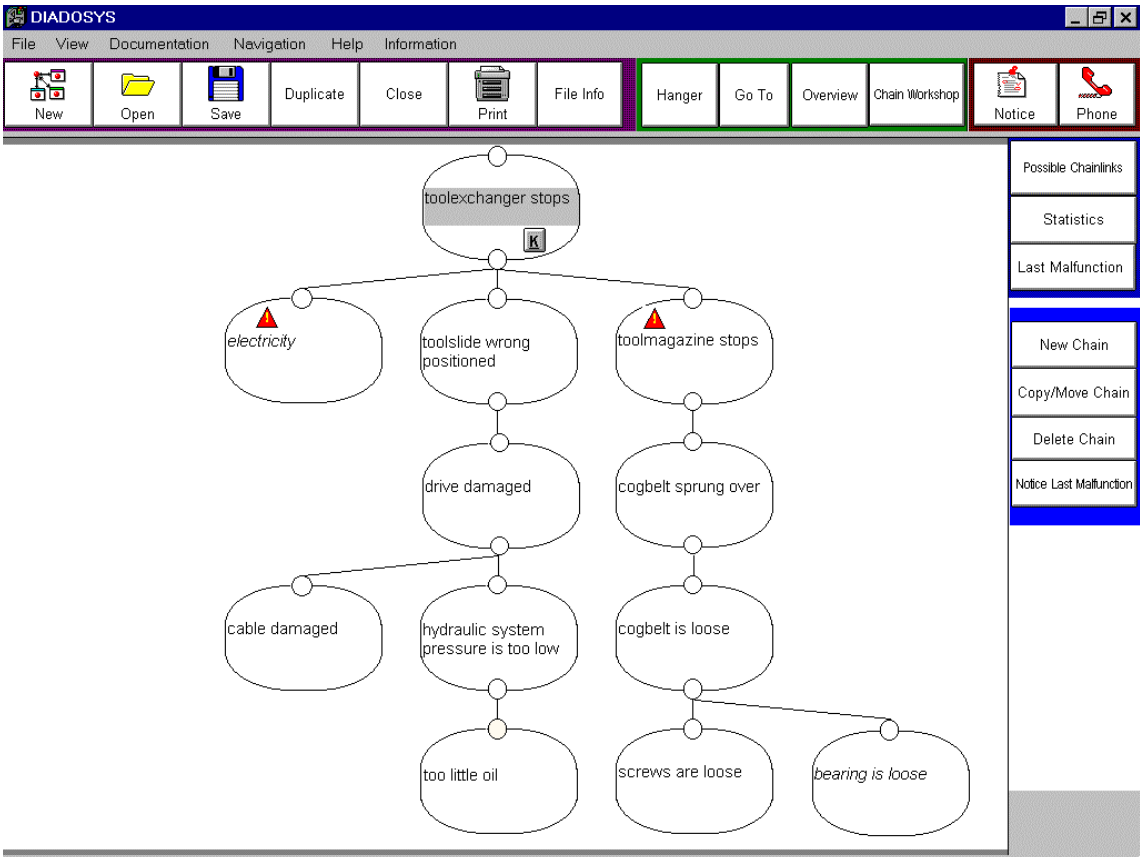

Figure 1: The system DIADOSYS: documentation of malfunctions as cause-and-effect interrelations

Participative design processes can enable the integration of work process knowledge leading to the design and production of simple user orientated systems. Our experience would suggest this can be particularly valuable in selecting which particular functions to develop and which can be left out of the technical specifications. However, while there is a considerable research on the participation of users within the design process there is a lack of evidence of reflection on practice and experience in this field.

There are a number of difficulties associated with participative design processes. First it would be unrealistic to expect prospective users to produce clear, well-defined technical specifications. Second even within organisations with post-Taylorist forms of work organisation users do not always wish to engage in the technical change of their work conditions. These difficulties can be surmounted if the design process involves co-operative analysis, between users and designers, encompassing the existing work organisation and the level of support desirable through the implementation of computer artifacts. Experience-based work process knowledge can be described as reflection-in-action [23], and it is this we want to encourage within the design process.

In principle, the system DIADOSYS can be used as a documentation system (the user documents the experiences which have proved to be relevant for his/her work) and as an information system (the user views the information which may be useful in his/her work situation). Each member of the maintenance department who is allowed to carry out maintenance and repair tasks can use the system for documentation purposes. Each worker has the opportunity to use the system for documenting those experiences that have been shown to be relevant for repair work. This is possible within an area of DIADOSYS called the "chain-workshop". Cause-and-effect-chains can be built up easily by using and describing chain-links which lead from the observations related to a malfunction to the basic reason of the fault. There are several possibilities to connect further information to these chain-links: security advice, repair devices, references to the user handbook and so on. New chains are stored in the chain-workshop until they have been verified and declared valid by a supervisory group (an interdisciplinary group of skilled maintenance workers) and they can then be transferred to the information structure of the system.

As a second step it is planned that production workers as well as maintenance workers will be allowed to use DIADOSYS as an information system. As an information system DIADOSYS can be used by navigating through the existing machine-specific cause-and-effect-chains. By using navigation functions a quick search can be made through the information base to find the reason for an acute malfunction - in the case where this malfunction has previously occurred and been documented. If this is not the case, the user might be able to draw conclusions from similar faults or he or she, in the worst case, has to recognise that there is no adequate information within the system at the moment. Then he or she can use DIADOSYS as a documentation system after having found the reason for the acute malfunction .

Our empirical studies have clearly shown it is worth establishing a better relationship between work experiences and the design and use of technical artifacts. At the moment a lot of fruitful work experiences are in danger of being lost, on an individual, collective and social level. Through the help of DIADOSYS we intend to encourage a process of documenting and communicating maintenance-related experiences of different users within a factory. It is also planned to use DIADOSYS for teaching and training purposes, as well as on a cross-company level. A producer of production line equipment for the car industry is a member of the project consortium and intends to integrate DIADOSYS within their product. Thus maintenance-related knowledge at the customer's site will be passed back to the producer in order to improve the quality of the product according to the experiences of the users.

Concluding discussion

Experience is an important element of maintenance workers' competencies in finding the reason for an acute malfunction quickly. The process of experience making consists of sensory perception, but interpreted by cognitive processes, and is memorised in various forms which are immediately useful for the work process, from (often implicit) sensory impressions and images to (often explicit) work rules. But experience-guided behaviour is made difficult under the conditions of computer-aided production environments, and maintenance workers need support in the process of troubleshooting. An approach, which does not try, to copy human abilities in the realm of skilled maintenance work but to develop a complementary tool is presented by the DIADOSYS system - it is a kind of collective memory containing documentation of those malfunctions which have occurred on a certain machine. The maintenance workers who use the system for documentation purposes have to translate their experience of a malfunction into a graphical structure and a verbal description. They are free, however, to fill in sensory related knowledge as well as analytical knowledge and in the description they may use their own common language.

The maintenance worker who uses DIADOSYS, in the case of an acute malfunction, may view the accumulated experiences which have been stored in the system. He or she is not obliged, however, to follow a certain work schedule - he or she has to draw her or his own conclusion in the light of the present situation. It is like the process of experience making, which we have described as reception of the object and, at the same time, as production of enriched concepts of the object. The only difference, if somebody uses DIADOSYS, is the enlargement of the memory upon which he or she can rely. It will contain information that calls things back into the user's memory and stimulates his or her imagination.

In the context of research and development activities we see our approach as a means towards a better relationship between work experience and the design of technical artifacts. There are in Germany only a very few examples of a work oriented design approach [9], which has a much stronger tradition in Scandinavia. We wanted to make a system available where the users from the shop floor themselves can fill in the information which is needed at work. One reason for the implementation of information systems on the shop floor is the high innovation rate and the rapid change in machinery and technical components within factories. Information about technology being stored in shop floor information systems has to be constantly kept up to date. Therefore shop floor personnel should have the opportunity to develop the "knowledge base" of an information system. This means opening up the design process for the shop floor workers, not only in relation to the user interface but also in terms of the functionality of the system.

Overall then this system offers a powerful means by which knowledge can be constructed and used in ways which are under the control of the skilled workers who are actually having to perform the required maintenance activities. The collaboration explicit in these processes could be extended beyond the boundaries of a particular firm. For example, the Bremen Craft Chamber of Commerce is interested in systems of knowledge creation, support and development which would be available to all their members, thereby facilitating collaboration and continuing professional development in circumstances when it is increasingly difficult for skilled craft workers to attend meetings arranged for staff development purposes. In order to achieve such a goal tools for knowledge construction have to be combined with tools explicitly designed to facilitate collaboration, such as those developed in the REM (Telematics in Europe) Project, outlined in a companion paper for this conference.

The combination of these two types of tools offers the prospect of supporting the development of a wider range of Knowledge Development Networks in Europe. Moves towards the development of the information society is leading to the recognition of ‘knowledge’ as a central demand for competitiveness for enterprises, and the involvement of networks is crucial for ‘knowledge creation’. Learning in networks links to continuing professional development for individuals and to organisational learning through the process of the creation, sharing, utilisation and dissemination of collective knowledge. The strategies, models and tools developed in the DIADOSYS, REM and related projects are designed to support networks as a key means of learning and managing knowledge development and transfer so as to support innovation and creativity. The integration of Information and Communication Technology tools for learning and communication is seen as important as learning and communication are two of the major issues facing European industries of all sizes. The outcomes of these projects can also feed into the development of more tailored tools to be used in support of new forms of knowledge creation, which are collaborative, forward looking and dialogical.

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