

Improving the Mastery of Work and the Development of the Work Process in Paper Production

L'amélioration de la maîtrise du travail et le développement des processus de travail dans les papeteries

Mejorando el control sobre el trabajo y el desarrollo del proceso de trabajo en la producción papelera

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Article abstract

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Improving the Mastery of Work and the Development of the Work Process in Paper Production

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The conceptual mastery of the work process and its improvement in the pulp and paper industry has been studied in several mills. Development programs based on systematic analysis and modeling of the work process have been used to improve the work process and the workers' conceptual mastery of it. The participants in the programs have made dozens or even hundreds of concrete proposals to improve the actual work processes and their conceptual mastery of the work process has increased. The results also suggest that conceptual mastery of the work process can be a source of positive well-being. This connection can happen during the development process showing that knowledge of the work process is really valued in the organization.

PAPER PRODUCTION AS A WORK PROCESS

Paper and board machines are the largest continuous-process machines in the world and paper chemistry is a very complex work process. The operators must be “very flexible in their problem solving behaviour, ... very ingenious in using all sorts of available knowledge when applicable, and [their] diagnostic performance increases with experience” (Schaafstal 1991). The paper-making process is also rapid, and the consequences of changes made at the “wet end” of the paper machine, for example, in the mass concentration or in the adjustments of the head box, can be seen only in the quality parameters of the paper at the “dry end” of the machine. Therefore paper-making involves not one single worker but a group of workers or a crew working on a paper machine. The work requires that all

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the workers of one paper machine observe the process both through the Visual Display Units (VDUs) of the automatic operation system and beside the paper machine itself, make hypotheses about the state of the process and the actions required from the personnel, and communicate their observations, decisions or actions to the other members of the group.

The subject of paper production is even broader than one crew. Delays are typical to the process. Sometimes it can take several hours to see the effects of a change made in the process parameters. The crews must therefore have an effective means of information transmission and, as a part of it, a joint understanding of the concepts of papermaking.

In the paper industry, the mastery of a work process and the mental model of the work process as a part of it have traditionally improved as a person has advanced in his or her career. The traditional distribution of work in paper production does not support the formation of joint conceptual models among the group of workers because, at the beginning of their career, the workers can get only information about some part of the process while working in their limited control district. Despite the demand for cooperation in paper production, the distribution of work has been based strictly on vacancies. Every worker has had his own "slice" of the production process to control. Career advancement has also been strictly regulated. During their work career, the workers have proceeded from the finishing of paper to the paper machine, and from the dry end of the machine to the wet end. Only the machine operators working at the wet end of the paper machine have been working on the whole area of the process and have attained a better conceptual mastery of the process than the other professional groups.

MENTAL AND CONCEPTUAL MODELS: A BASIS OF COOPERATION AND COMMUNICATION

The concept of a mental model or a related concept has often been used to describe the mental functions by which the workers control and operate the process, or as one worker states in Zuboff's (1988: 86) study, "You have to have a mental picture of what is going on behind the indicators." The concept of a mental model is not unambiguous however. It has been used in studies of work in complex processes (Doyle and Ford 1998), but the vague use of the concept of a mental model has also been criticized (see, for example, Norman 1983; Farooq and Dominick 1988; Bainbridge 1992; Staggers and Norcio 1993). It has been considered important to separate the models used by people having different roles in the work process. In particular, the conceptual model of the target system and the user's mental model of the target system should be separated. A

conceptual model is invented by teachers, designers or scientists as an accurate, consistent and complete representation of the target system. Mental models are created by users as they interact with target systems and may, or may not, be equivalent to conceptual models (Norman 1983; Staggers and Norcio 1993; Vicente 1999). Nevertheless, in a complex process involving not only one person, but a group of people, cooperation and communication of the group requires accurate, and mutually accepted concepts to be able to exchange information in the critical phases of work processes, e.g. during production disturbances (see also Vicente 1999). Accurate concepts and sufficient knowledge of the work process are also prerequisites for learning from the process events and for sharing experiences and knowledge in the work community to improve the work process further (Vicente 1999).

In the paper industry, the educational backgrounds of the workers still vary from no vocational training to a vocational training of three years. Variation in education, work experience, the potential of the environment and the organization to support learning, and in the individual learning orientations is great. As a result, the mental models of the work process vary considerably. Therefore the first step towards better mastery of the work process should be the creation of conceptual mastery of the work process that support communication within a crew and between the crews, between production workers and workers in the related work processes, and between the workers and various experts of the mill.

DEVELOPING THE MASTERY OF WORK BY DEVELOPING THE WORK PROCESS ITSELF

The mastery of complex dynamic systems has previously been improved either by traditional classroom training based on the lectures of various experts or by simulator training. Pilots, operators of nuclear power plants, and other workers in safety-critical complex environments have participated in studies on the consequences of simulator training on learning and the operators' habits of acting (Hukki and Norros 1998). Studies on learning at the shop floor level are, however, rare even in the complex process industry, and deal either with the outcomes of massive training programs organized before the start-up of a production line (e.g. Nurmi 2000) or with a limited group of workers, usually those regarded as some kind of experts. Interest in adult learning on the shop floor has, however, increased with the pressure to create learning organizations that can survive with intense competition. But how do adults learn, and how can learning be enhanced?

Engeström (1987: 137) has suggested that the ontogenetic emergence of learning activity also takes place in adulthood, when the subject faces

historically and individually pressing contradictions within his or her leading activity, e.g. in work. Learning was defined as a consequence of “making cycles of expansive transition, i.e. collectively mastered journeys through zones of proximal development” (Engeström 1987: 336). In practice, this has meant that researchers have tried to reveal the development dynamics of the activity and new prospects for development, by analyzing the changes in work historically and finding elements of a more developed practice in the activity. This approach regards human cognition as constituted in a social and practical context that has meaning for the actor (Norros and Hukki 1996). The aim to apply analysis of a work process as a tool is therefore to increase the workers’ ability to see the work process as a whole and to take an active part in forming it. The work process is developed through the workers and with them (Norros 1996; Virkkunen 1995). So this approach is at the same time a tool for developing work and a training method based on the systematic externalization of the personnel’s knowledge. This does not mean that any conception or opinion is regarded as fact, but all information is also analyzed from the viewpoint of usability, reliability, dependability and development of the whole production system. This means that the workers must adopt the orientation of a scientist or a designer (e.g. Norros 1989), and use conceptual models of the work process as tools in the analysis of their own work. The adoption of an inquiring orientation to the object of learning has lately been considered a key factor in learning (for example, Hakkarainen, Lonka and Lipponen 2000). An inquiring orientation towards learning, and towards learning one’s own work must, however, also be learned and requires, among other things, that the environment, work process and organization create opportunities to learn or support learning.

DEVELOPMENT PROGRAMS TO IMPROVE CONCEPTUAL MASTERY OF PAPER MAKING

In the Section of Ergonomics at the Finnish Institute of Occupational Health, the consequences of technical and organizational development on the mastery of the work process and its improvement in the pulp and paper industry have been studied since 1985. The main interest has been in the simultaneous development of the work process and its conceptual mastery. Research in this area began when we started to study the introduction of an automatic operating system in a paper machine (Leppänen 1989). At the same time, the product of the machine had also been changed from newsprint to fine paper. When the renovated production line was started, production disturbances occurred frequently, and the line could not attain the planned volume of production. Because of the problems encountered, the control of the production system was replaced by strenuous physical

work (Louhevaara et al. 1991). After several days of observations, and after scrutinizing the training program implemented before the start of the renovated production line, it was obvious that the operators' mastery of the production process was not good enough to direct the control and operation of the production process (Leppänen 1989, 1991).

A development program based on the analysis of the work process and its development needs was planned to support the improvement of the workers' mastery of the work process and the development of the work process itself. This methodology has now been applied in 15 of about 100 paper or board machines in Finland. Finishing processes like paper cutting have also been analyzed and developed with a similar approach in some paper and board mills. Development programs are based on the analysis of the work and the production processes. The elements of human activity at work (e.g. Engeström 1987), the outcomes and object, tools and division of labour are analyzed. As for the subjects of paper making, the crew's ways of acting in various situations and their co-operation within the work process and with the related work processes, e.g. maintenance, quality control, etc., are analyzed as well. The researchers define the basic categories to be used, or questions to be answered, when constructing the models. Drawing on written material, technical drawings and other information on the production process, and on observations and interviews of the workers' work activities, these categories are based on the preliminary conceptualizations of the work process. During the program, the participants analyze the production and work processes. They are instructed to do the analysis from the viewpoint of work activity. The histories and starting points as well as the actual production and work processes vary from one machine line to another. Because of the contextual nature of the development program, it must be tailored for every case separately, although the principles of paper-making remain similar from case to another. In our first case we started in a situation in which the renovation process had not been successful enough (Leppänen 1989). The development program was also conducted in a board mill aiming to get the first ISO-9001 certificate in a paper mill in the country. The management of the mill wanted to make sure that the best practices were to be certified and that the personnel of the mill were capable of working according to them (Leppänen 1993). The initial impetus to start a program has very often been the desire to improve the mastery of the entire work process.

The development programs and their didactic principles

Participants

The five crews and foremen of the machine line form the collective subject of paper making. They are therefore the main subject of the

development and learning process as well. During the program, each crew and its foreman work as a group externalizing its own models of the parts of the work process. During this process the crews learn to use all the knowledge available in the group. The models constructed are verbalized representations of the work process, and they are written down in a file, in order to allow all the group members to follow the development of the group's thinking and to compare their own models to the final models drawn up on the basis of the models of all five crews, and of the discussions in the large groups.

The production manager and the production engineer of the production process, the experts of process chemistry, the experts of automatic operation system engineering, and the marketing officer participate in the development program discussions on the basis of their own expertise. Their role is twofold. On the one hand, they are part of the work community, and broadly speaking the subject of paper production, and therefore they must participate in the development of those phases of the entire production process with which they work. On the other hand, they serve as informants or theoretical advisers on questions dealing with discrepancies in the work process, e.g. some quality parameters of paper may be difficult to attain, but the customer still requires these parameters. The sales personnel can usually explain the reasons for the requirements. Engineers, chemists and other technical experts can give theoretical explanations for the process phenomena and predict their controllability from the viewpoint of technology.

Structure and Contents of the Programs

The development program is usually organized in four 2-day sessions. Pauses between the sessions are reserved for rethinking the issues handled, and for collecting empirical data for the future sessions. Each session is arranged twice as, because of shift-work, either 2 or 3 shifts participate in each session. The models prepared by the crews participating in the same session are discussed in a larger group including the crews, other experts related to the production process studied, and the researchers or trainers. The crews learn from each other and also from the questions of other participants. They also learn to ask questions to the various experts and the material available (e.g. technical drawings) regarding the issues studied. The same groups do not participate every time in the training with each other, and this gives all crews a chance to work with all the other four crews in order to improve their co-operation and communication, as these skills are crucial during the change of crews at work. When a shutdown of a line has occurred, all five crews have sometimes participated in the program. This is an ideal way of tackling a problem.

TABLE 1
The Structure and Contents of the Development Program

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1. Analysis of the products, raw materials and additives and their interrelations
 2. Analysis of the main phases of the production process (for example, paper making)
 3. Model of the paper machine and analysis of the activities of its main functional parts
 - their functions in the process
 - essential characteristics of every functional part
 - methods and tools to control these functional entities
 - probable malfunctions in a functional part
 4. Analysis of the work activities during the critical tasks in paper making
 - control of normal functioning
 - analysis and elimination of disturbances
 - change in the grade or other characteristics of the product
 5. Analysis of work organization and division of work
 - tasks of the occupational groups
 - cooperation with the maintenance workers, workers in quality control and marketing
 6. Analysis of the development needs in the work process and plans of the development actions
 - ideas for development needs (these came up during the previous phases of the program)
 - proposals for developmental action
 - positive and negative consequences of the proposed action
 - prerequisites for the realization of the proposed action
 - decision on the realization or rejection of the proposed action
 - nomination of the executor for the action
 - schedule for the action
-

During the program, the work process and its development needs are analyzed with the aid of models representing the work as an activity. Products and raw materials, the object of work, are analyzed first (Table 1). Externalization of the knowledge concerning the actual work process is the first phase in the construction of every model. This is done by listing, for example, the products of the machine line. With the help of the production engineer, the basic lists of two or three crews form a comprehensive list of the products. When the participants have reached agreement on the products, they start to analyze the use of the product, the related requirements for quality parameters, and why (Table 2). The next question deals with the special requirements for the way of acting when the product is made. The potential problems in production are also analyzed, as well as the proportion of the product in the entire volume of production. The

models of the raw materials and the machinery used are analyzed in a similar way (Table 2). In this process, the crew members' different views of the functions and characteristics of this part of the process emerge and complement the mental models of the participants. But incorrect or stereotypical ideas or views may also be reinforced. To avoid this, after finishing their proposition for a model, the crews also analyze their models together with the experts on the issues dealt with. For instance, the model of raw materials, their functions in the process, effects on the quality of the product and the production process in a normal situation, and in the case of over- or underdose, are analyzed with the production engineer and the chemist responsible for quality control in the laboratory. These analyses support the improvement of the crews' conceptual mastery of the chemistry in paper making and sometimes lead to the need for a deeper understanding of the principles of chemistry.

The phases of the production process are analyzed from beginning to end. The analysis of paper-making starts from the point when the control of the pulp is transferred from the pulp department to the paper makers. The aim of this phase of the program is to improve the conceptual model of production process and the principles of paper making in general. This analysis is needed because the processes are nowadays so complex and hidden that the workers cannot observe the phases of the process in practice. Sometimes old paper making processes are also analyzed from videotapes. These show that although paper making is now both complex and vast in scale, the basic process phases have remained the same for decades. The history of paper-making and the phases of the production process that require improvements and technological innovations are also discussed.

In the model of the paper machine (Table 2) the functions of every part in the production process are analyzed. The crews analyze why every part is needed in the machine and what are the characteristics of the part in question, and what makes the part capable of performing its task. The characteristics of the part are also analyzed from the viewpoint of the usability and reliability of the production process. Because the functioning of technical devices is usually described by the means of technical drawings or formulas of physical phenomena, the participants customarily use these modeling tools to specify the functioning or characteristic of some part that is difficult to understand.

The interface and man-machine interaction is analyzed by asking the following questions:

- What function or characteristic of the part is changed during production or in certain situations (for example, the level of the surface in a tank or the revolution speed of a pump)?

- How the function or part is operated (automatically or manually) and where (in the control room or near the machine)?
- What information is available on the part and its functioning and how is it distributed? What is the sufficiency and usefulness of information in various situations?

The quality of the man-machine interface is often analyzed further. The possibility to control the functioning of a part and the appropriateness of the control devices has been analyzed. The machine, automatic operation system and the allocation of tasks between the human operators and the automatic operation system are analyzed to improve the workers' conceptual mastery of the principles of the functioning of the technical system and its limitations and development needs.

After this the crews analyze the critical situations arising in production (Table 1). Disturbance situations, changes in grade, shutdowns and start-ups of the process are analyzed on the basis of the tasks derived from real-life information, videotapes of actual work activities, or various simulations of the situations. At this phase of the program, the use of the new conceptual tools adopted during the construction of the various models can be rehearsed in the analysis of activity in critical work situations.

Paper making is a complex system and therefore requires people to work together to make the process function properly. Analysis of the organization and division of work leads to the analysis of co-operation and communication within one crew, between the crews of one machine, between the crews of the related production processes, for example pulp mixing, and also between the personnel in production, production planning, maintenance and quality control. The issues vary to some extent but in all cases an analysis is conducted of the co-operative situation or question dealt with, the participants and the means of co-operation (Table 3).

During the analyses of co-operation the participants learn a lot about the requirements of the related work processes. The participants also learn to ask questions about the work processes of other teams and, very often, the participants create new ways of acting in various co-operative situations.

Every development proposal that comes up during the analysis will be specified further (Table 1). Reasons for the proposal, alternative proposals, the benefits and disadvantages of the proposals, and the necessary resources required are discussed. After a joint view of the required actions is formed, the organizational level on which the decision could be made will be defined and the decision will be made. Finally, those responsible for implementation and the schedules for the proposed actions will be defined. The thorough analysis of development proposals is important, because the participants learn that they can, through systematic analysis of

TABLE 2
 Examples of Models Created during the Analyses of the Paper Making Process

<i>Product Model</i>						
<i>Product</i>	<i>Use</i>	<i>Special Requirements</i>	<i>Special Considerations in the Means of Controlling</i>	<i>Potential Problems occurring in Production</i>	<i>% of Production</i>	<i>Development Needs</i>
Backing paper	to be coated in conversion	good thickness profile, because the product will be punched out after coating no holes, twist, eccentricity or pleats	must be sufficiently ground		8	
Magazine paper	magazines, printed advertising material	consistency, no pinholes, gloss xx %, bulk xx	amount of pulp xx %, grinding xxA, minimization of the use of reject, cut down fixative, cut down suction, frequent washing of the counter reel. Drive overweight x g/m2 on machine		11	
<i>Raw Materials, Additives, etc.</i>						
<i>Substance</i>	<i>Effects on Quality</i> <i>Effects Desired (a)</i> <i>Effects of Overdose (b)</i> <i>Effects of Underdose (c)</i>	<i>Effects on Runnability</i>	<i>Dosing</i>	<i>Place and Manner of Dosing</i>	<i>Price</i>	<i>Development Needs</i>
Bolus alba	(a) lowers raw material costs, fills and improves paper base formation.	improves drying decreases runnability to some extent	4-6 l/min	automatic dosing		measurement of dosing operates unevenly

	(b) increases ash values, improves the printability of paper (c) decreases strength of paper	chokes suction reels and felts decreases retention sticks to drying cylinders							
Titanium	(a) improves opacity and brightness (b) process devices get dirty, increased number of pinholes (c) less opacity and brightness	decreases runnability by dirtying the system and weakening the strength of paper	3-5 l/min	before the fan pump	\$2500 / ton				

Parts and Functions of the Machine

<i>Part of the Process</i>	<i>Functions of the Part</i>	<i>Features</i>	<i>Object of Control (o) Place to Control (p) Way to Control (w)</i>	<i>Alarms</i>	<i>Who Operates Controls</i>	<i>Development Needs</i>
2-Fan pump	pumps pulp to the head box through press bolter	a big vane pump, cycle speed can be controlled	(o) cycle speed (p) automatic operating system (w) automatically	does not run overload	machine operator	adjusting the web guard should be less strenuous
Pick-up-roll	removes water from the web acts like a suction fan, transforms paper, with the help of suction to the press	three suction sections, own guard for every section, vacuum suction pump to remove water, changeable roll the internal part of the roll stays still, and the coat rolls, blade included in the roll	(o) border limiters suction inlets (p) panel in the control room, (w) automatic manual operating system	alarms of the function disturbances in suction pump through automatic operation system	machine operator	
Intermediate calender	leveling and compactness of the web	contains 2 different rolls and a pump to control pressure	panel next to paper machine	pressure and heat of oil, velocity difference, tightness of paper	cylinder man	

their actual work process and its development needs really affect the development of their work. But they also learn that although there may be development needs in some part of the process, their realization can cause problems in some other part or function of the system, or the analysis may reveal that technological innovation is required to solve the problem or develop the process further.

EVALUATION OF THE CONSEQUENCES OF THE DEVELOPMENT PROGRAMS

Evaluation of the consequences of development interventions, such as training, in work life is increasingly important (Warr, Allan and Birdi 1999). The evaluation should cover the subjective reactions of the participants regarding the training received, learning and job behaviour. The consequences on organizational indicators, such as productivity, quality and staff turnover should be measured, but this is difficult because the organizational indicators mentioned are affected by several factors that cannot be controlled or measured. This is why systematic evaluation of organizational indicators “has hardly ever been reported” (War, Allan and Birdi 1999). In the studies on the consequences of the development programs described in this article, the outcomes of the programs have been evaluated at several levels.

Development of the Work Process

Several development proposals come up in every development program. They are analyzed according to the reason or aim behind the proposal and according to the object or content of the development proposed. There are three classes of aims: elimination of problems affecting system efficiency, elimination of problems lowering quality, and further development of the system efficiency and the quality of the products.

The objects or contents of the development proposals vary according to the historical development phase and the culture of the work process and organization. However, proposals dealing with the technical development of the system, improvement of competence, or the personnel’s way of acting, and improving the co-operation between different personnel groups have come up in most of the cases. In some cases proposals to improve the work environment have also emerged.

Learning

The main target of the development programs is to improve conceptual mastery of the work process. In the development programs, the outcomes

TABLE 3
Examples of Analyses of Co-operation between the Crews and within One Crew

<i>Co-operative Situation or Question Dealt With</i>	<i>Participants</i>	<i>The Means of Co-operation</i>	<i>Development Needs</i>
Change of the crews	Machine operators, reel men and foremen, each professional group separately	Discussion of a few minutes; the departing crew reports the changes going on in the process and informs about future critical changes in the process The machine operators may also check some details in the field although the discussion takes place in the control room	Because there is no mutually agreed way to act during the change of the crew, it is often a chaotic situation in which important information remains undelivered
The means to reach quality parameters in a special situation	The machine operator and the cylinder man	Asking questions and answering them, discussing alternative ways to reach the parameters	All the other workers of the machine and the foreman should participate, because they may have experience of similar situations

in terms of learning have been evaluated by measuring the conceptual mastery of work and the mastery of disturbance handling, and by analyzing the level of learning that the development proposals represent. The measurements have been made before and after a development program.

The conceptual mastery of the work process is studied with diagnostic tests. The methods aim to measure the knowledge of the permanent or potential characteristics of the target system saved in the long-term memory. The questions deal with the object of work, the functionally important characteristics of the paper or board machine, essential quality parameters and the factors affecting them, factors affecting production economy, and the relations between, for example, the functioning of the machine and some quality parameter (Table 4). The production manager and the production engineer of the machine give the correct alternatives for the questions and the answers are coded accordingly. The tests have ranged from 71 to 200 items and a sum score is used to assess the percentage of correct answers.

The mastery of disturbance handling is studied with a paper simulation of actual disturbances. The subjects get a copy of real production instructions and information about the measured quality parameters. They are first asked to use this information to diagnose the situation. For example, is there something wrong, must something be changed to reach the required test results? Then they are asked to analyze the measures used to recover from the disturbance. The disturbance situations are constructed so that the reasons for the disturbances can be deduced from the information given. The production engineers of the paper machines formulate the model answers for the disturbance tasks.

The proposals for development are analyzed from the viewpoint of *the levels of learning* that they represent. The levels of learning are analyzed from simple adaptation to higher levels of learning.

Consequences on Well-Being

Research on the mental models, competence or work-related knowledge of the workers and their well-being have generally been separate topics of investigation. Already 20 years ago, it was hypothesized that inaccurate mental models are related to mental overload (Bainbridge 1978; Johansson and Gardell 1978; Hacker 1982) and the association between comprehensive mental models and low short-term stress has been demonstrated (Vihmalo 1986; Järvenpää 1986). The association between work-related mental models and long-term well-being is, however, more complex. Several models of job stress and job satisfaction share the idea that the perceived consequences of work on the well-being of an individual are the result of complex processes, including the objective characteristics of the environment, their subjective assessment, objective competence of the

TABLE 4
Examples of Questions in Different Categories of Conceptual Mastery*

Object of work	The offset paste contains: – talc – bolus alba – sb-latex – acrylate-latex – glyoxal – starch
Functionally important characteristics of the paper or board machine	The drying cylinders dry paper most effectively: – when there is a thin layer of condensation water inside the cylinder – there is no water in the cylinder – the cylinder is full of water – the web presses tightly against the surface of the cylinder
Essential quality parameters and the factors affecting them	How does the surface size affect the quality parameters of board: – diminishes the fluffing of the board – increases bonding strength of the surface – hides the faults in the board – speeds up the production of board
Factors affecting production economy	The cost of paper rises when: – the chemical pulp layers become thicker – the amount of talc increases – the beating of mechanical pulp increases – the dehydration ability of the press felts and drying wires decreases
The functional relations between the functioning of the machine and some quality parameter	Do the following factors affect fiber orientation: – spray ratio – speed of the wire – pulp concentration – temperature of the drying section – edge showers – pressure of the head box

* Every question or sub-question has three alternative answers: I agree, I disagree, I don't know.

person to act or cope in the situation, and his/her appraisal of these competencies. The connections between objective and subjective mastery of work, assessments of their work and experiences of well-being, and their development during the program have been studied to assess the consequences of the development program on the metacognitive assessments of the factors affecting a person's reactions, such as satisfaction or stress, to his work. *The Occupational Stress Questionnaire* (OSQ) (Elo et al. 1992) and questions dealing with the workers' own appraisals of their qualifications to participate in the development of their own work process has been used to follow up the subjective assessments of work, well-being and qualifications during the development programs.

SUMMARY OF TWO EMPIRICAL STUDIES ON THE OUTCOMES OF THE DEVELOPMENT PROGRAMS

Study 1

In a follow-up study, the outcomes of the development program were examined with the methods described above. Conceptual mastery of the work process and the mastery of disturbance handling were studied before and after the development program. The following questions were addressed. First, what is the level of the conceptual mastery of the work process in paper production and how does it change during a development program based on a systematic analysis of the work process? Secondly, is the conceptual mastery of the work process related to the experience of well-being on the part of the workers? Finally, does the level of conceptual mastery or experience of well-being vary according to the occupational group or work group?

The workers and foremen ($n = 22$) who formed the five crews operating a board machine participated in the study. All the subjects were men and their mean age was 43.5 years (sd 7.9). Seventeen of the subjects had worked in the mill for over 15 years and five subjects for over 3 years. The number of participants varied both with occupational group and the crew (Table 5).

TABLE 5

Number of Participants by Occupational Group and Crew

<i>Crew Number/Occupational Group</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>Total</i>
Foremen	1	1	1	1	1	5
Machine operators and cylinder men	2	2	2	1	2	9
Reel, mass and reserve men	–	–	3	3	2	8
Total	3	3	6	5	5	22

Because of the small number of subjects in some of the occupational groups, the occupations were classified according to the phase of traditional career advancement. For example, the foremen were technicians and, due to their education and position, they formed one group. The machine operators attained their vacancy after having worked as reel or pulp men and as cylinder men. The cylinder men also substituted for the machine operators. The reel, pulp and reserve men work either at the “dry” or the “wet” end of the machine. They formed the third group.

Statistical Methods

The changes in the results of a group in the conceptual mastery of work, and in the self-assessments of work and well-being were studied with Wilcoxon's test. The relations of the conceptual mastery of work, mastery in disturbance handling, development orientation, assessment of work characteristics, and perceived well-being were analyzed with Pearson's product-moment correlation coefficients. Although the measurements were on an ordinal level, the possibility that the variance of the measures of well-being is explained by several variables was studied with regression analysis in the second phase of the study. The relations between the variable groups were studied separately for the whole group ($n = 22$) and for the group of workers ($n = 17$).

Results

Conceptual mastery, mastery of disturbance handling, and their development. Before the development program, 65% of the answers to the diagnostic test measuring conceptual mastery of the work process were correct, whereas afterwards 79% of the answers were correct; 18 out of 22 subjects had a better result in the second measurement than in the first one. The change was statistically significant ($p < .001$).

TABLE 6
Changes in the Conceptual Mastery and their Statistical Significance
in the Occupational Groups

<i>Type of Change</i>	<i>Improved Ranks, Better Mastery</i>	<i>Worse Ranks, Worse Mastery</i>	<i>Ties, No Change</i>	<i>z</i>	<i>p</i>
Foremen	3	1	1	-1.46	.144
Machine operators and cylinder men	8	1	0	-2.55	.011
Reel, mass and reserve men	7	1	0	-2.38	.017

The occupational groups differed in their conceptual mastery of the work process before the development program but not after it. Both worker groups increased their conceptual mastery of the work process by statistically significant margins (Table 6). The conceptual mastery of the work process did not increase in the foremen's group, but it was high (80%) even before the development program. The professional groups did not differ from each other in disturbance handling in either of the measurements. However, when the development of the diagnoses and analyses of the disturbance situation were analyzed qualitatively, some differences in the development of the mastery of disturbance handling were noted between the groups. Before the development program only one foreman and two machine operators made a comprehensive diagnosis and analysis of the situation. After the development program, seven subjects both diagnosed and analyzed the disturbance situation comprehensively and two of them came from the group of reel men. The crews did not differ from each other in either research phase with respect to mastery of the work process.

Appraisals of work characteristics, subjective development qualifications, and the indicators of well-being. The assessments of work characteristics and well-being were positive both before and after the development process and they did not change significantly during the development program. To some extent, the subjects wanted to participate in the development of their work both before and after the development program. After the development program, the participants felt that they were more qualified to participate in the development of their work ($p < .05$). There were no differences between the occupational groups or the crews in their assessment of their work characteristics or subjective well-being either before or after the development program. There were also only some suggestive differences between the assessments of the work groups.

Relationships between the mastery of work, subjective assessments of development qualifications, work characteristics, and well-being. A prerequisite for health and well-being at work is that the objective work process itself is not hazardous to the workers and supports the development of competence. Secondly, the workers' assessment of their work process should be realistic. Thirdly, they should have the means to act in the situation and to control it. Finally, they should appraise these means adequately. If the work is unhealthy, if its mastery is poor or if the appraisal of work or its mastery do not correspond to the reality, problems can arise in the well-being of workers. A low level of disturbance handling was related to a high level of self-assessed qualification in work development before the development program started. The workers who were better at handling disturbances experienced more stress and less competence than did the workers with a lower mastery of disturbance handling.

After the development program, a high level in the mastery of disturbance situations was related to job satisfaction. The other indicators of subjective well-being, for example stress, were not related to the conceptual mastery of work nor to the mastery of disturbance handling. In the regression analysis of the workers group, 72% of the variance in job satisfaction was explained by mastery of disturbance handling, together with a positive appraisal of the challenges at work and an active outlook towards work development.

Development needs and the level of learning. Most of the development proposals made during the program dealt with the improvement of the technical production system because of problems in system efficiency and, consequently, the productivity of the system (Table 7). The majority of the proposals aiming at the improvement of problems affecting the quality of the product were technical in nature. But the proposals aiming at the further development of system efficiency and product quality dealt mainly with co-operation with personnel.

TABLE 7
Number of Developmental Proposals by Object and Solution

<i>Object of the Proposal/The System Solution</i>	<i>Technical Production</i>	<i>Competence or the Personnel's Ways of Acting</i>	<i>Technical System and the Personnel's Ways of Acting</i>	<i>Co-operation with the Production Personnel, Maintenance and Quality Control</i>
Problems affecting the efficiency of the system	55	15	7	22
Problems affecting the quality of the product	19	9	4	
Further development of system efficiency and product quality			3	16

The proposals to improve the technological production process started from the perception that the technical system did not work as originally planned or that there were ergonomic problems hindering the working. The primary ideas were sometimes quite fragmentary but when the personnel of the machine line analyzed them systematically, concrete, feasible solutions emerged. Most of the improvements were scheduled at once and implemented during the program. However, proposals to improve the

technical system to function as it should, represent only the lowest level of learning, for instance mere adaptation to the context.

The proposals to improve the crews' ways of acting or to increase cognitive mastery of the process dealt with the improvement of the documentation of process history or with the need to get more information on the measurement of quality parameters. These proposals indicate that the participants also regarded their own activity as an object of development and that the need for a thorough understanding of the work process has also increased. This indicates that the object and motive to work were growing.

The proposals aiming at the further development of the work process dealt mainly with the improvement of co-operation between different organizational parts (Table 7). Paper-making as the core work process is dependent on several other work processes in the organization. Production planning gives paper makers their production program, the concrete goal of their activity. The workers in maintenance ensure the usability of the paper machine, the papermakers' tool, through preventive maintenance and repair of faults. The laboratory assistants measure the quality parameters of the paper, the object of the papermakers' work, and inform them about trends and deviations in the parameters. The efficiency of the system depends on the co-operation between these work processes. But when dozens of people worked in every process, the joint goal of the different work processes was not clear enough. The proposals aiming at better co-operation included both the improvement of work activities and the division of labour, but also the need to understand better the internal logic of the related work processes.

Study 2

The results of the development program based on the modeling of the work process were studied in another paper mill in which a new paper machine was built. New paper production lines are very attractive potential workplaces in Finland. Only a small proportion of the applicants can be recruited. New production lines are most often established in an old paper-mill and part of the personnel of the old production lines usually come to work on the new one. The establishment of a new production line is regarded as a possibility for the workers' career advancement and observations of the recruitment strategies during a technical change process indicate that the "creaming" principle has been adopted in most cases. In the case studied, the personnel of the new paper machine were selected with the aid of psychological aptitude testing from 1000 applicants. A considerable number of experienced workers from the old production line came to work on the new machine and, as a result, the productivity of the old production line declined. In order to remedy the decline, the produc-

tion manager ordered a program based on a modeling of the work process to develop the work process and the conceptual mastery of it. The workers, the foremen and the production engineer and development engineer of the machine participated. At the same time, the personnel of the new machine line participated in an ongoing program lasting for several months.

The conceptual mastery of work in both groups that stayed on the old production line and those leaving for the new one were followed up. The two basic groups were also compared with the new groups coming from outside. The following questions were addressed. First, did the group of workers staying on the old production line and the group of workers transferring to the new line differ from each other in their conceptual mastery of work, in educational background or in other demographic variables or in their subjective assessments of work, job satisfaction and their subjective symptoms of stress before the building of the new production line or two years after its start-up? Secondly, did the group of workers staying on the old production line differ from the newcomers on the same production line in any respect studied? Finally, did the group of workers transferring to the new production line differ from the other workers on the production line in any respect studied?

Design, Material and Methods

This study followed up the groups staying on the old production line ($n = 23$) and those leaving for the new one ($n = 18$), 62% of the subjects in the first measurement also participated in the follow-up. This study was also cross-sectional. The two basic groups were compared with each other at two different points of time and with the new groups coming from outside ($n = 37$ for the old production line, 60 for the new one). Altogether, 79% of the personnel on the old production line and 91% of the personnel on the new one participated in the study.

Results

Those who stayed on the old production line were statistically significantly older ($p < .01$) than those who moved to the new line and also older ($p < .001$) than the newcomers to the old production line. Those who stayed on the old production line were also less educated than the other three groups.

Those who stayed on the old production line felt more competent in the second measurement to participate in the development of their own work than in the first measurement. They also assessed their work as more challenging, were more satisfied with their work, experienced their future as more positive, and their work environment as better in the follow-up

measurement. Those who transferred to the new machine line were also more satisfied with their work and work environment in the follow-up. They also felt that their control over their own work had increased.

There were very few differences between the groups in the first and the follow-up measurement. There were no differences between the groups in the conceptual mastery of work or in the assessments of work characteristics, job satisfaction or other indicators of subjective well-being measured by the sum scales.

DISCUSSION

The complexity of paper making has increased continuously and includes most of the features of a complex system (Vicente 1999). For instance, the object of work, that is the process itself, is dynamic and the tools used include automation and other information technologies that have increased the mediated nature of information. The process is vast and is controlled by a collective subject. Yet disturbances do occur and hazards do exist. The human operators try to anticipate future situations under conditions of uncertainty. Although the work of the process operators is very demanding, the practices to create and improve professional competence in paper mills have varied a lot and problems related to inappropriate training practices have occurred (Leppänen 1989). The development program to improve both the workers' conceptual mastery of their work and the work process itself was developed 15 years ago to help the personnel of one machine line to remedy the problems caused by an unsuccessful technical renovation process. The program is based on systematic analysis of the work process, an approach proved to be adequate in work development (Virkkunen 1995) and also suggested for analysis prior to the design of a complex system (Vicente 1999). The didactic solutions of the program included the following observations. The subject of learning is the subject of work. The crews that make the paper also learn as a group. The object of learning was the work process and the content and method of learning was the analysis of the work process and its development needs through the externalization of the work process. In the conceptualization of the work process, different viewpoints and theoretical approaches to the object of analysis were utilized. The outcomes of the development programs have been evaluated at several levels in two empirical studies.

Learning Outcomes

The results of the first follow-up study on the outcomes of the development program indicate that the conceptual mastery of the board-making

process can be improved by a development program based on systematic analysis and modeling of the work process. The workers' conceptual mastery of their work improved. In particular, those who had less education and experience benefited from the development program. It has been shown previously that novices learn a lot in a joint process of externalizing and correcting the knowledge of the work process and the ways of analyzing the strategic phases of the process. Seifert and Hutchins (1989) described how the novices in navigation learn while observing and participating in the open handling of errors. Later Roth and Kleiner (1998) stated that open dialogue was a catalyst in the process of making oil refinery workers into practitioners. During the analysis of the paper making process, the participants externalize their knowledge of a complex production process, and the inaccuracies and mistakes in the externalized mental model are corrected in an open process, which also offers all the crew members an opportunity to learn from the mistakes of others. Nevertheless, the conceptual mastery was not perfect in any of the occupational groups of the first study nor in any of the groups studied in the second study. This shows that there is a continuous need to analyze and develop work in complex production processes.

Proposals for Work Development and Learning

The participants in the first study made more than 100 proposals to develop the work process further and so did those who participated in the development program in the second study (Leppänen 2000). The development proposals deal with the entire work process from technical development to the co-operation between various professional groups. The development proposals come up in a systematic analysis of the work process and they are refined further in a systematic process. They therefore represent actual development needs in the work process and provide adequate information to start developmental actions. They are not merely occasional ideas, nor the views of one person sometimes used in the participative design of a work process, resulting in mostly negative consequences (Vicente 1999).

The development proposals were also analyzed from the viewpoint of the learning they represented. The majority of the proposals aimed at the development of the technical production process. The proposals to improve the technical system to function as it should, represent only the lowest level of learning, that is mere adaptation to the context, whereas the proposals to improve the ways that the crews act or to increase the cognitive mastery of the process indicate that the participants also regarded their own activity as an object of development and that the need to understand thoroughly

the work process and its imperatives has increased. This indicates that the object and motive to work were both growing. However, some aspects of large technical production processes always break down or can be developed further. Therefore development needs will emerge in various parts of the system. But continuous analysis of the work process as a human activity is needed to increase the understanding of the opportunities to develop the ways of acting in various situations and the metacognitions concerning them.

Improvement of Metacognitions and Support for Well-Being

It was hypothesized that well-being at work requires positive work characteristics, good conceptual mastery of the work processes and their realistic appraisal. In the first study, these relationships only emerged after the development program. A high level in the mastery of disturbance situations was then related to job satisfaction. The other indicators of subjective well-being, for example stress, were not related to the conceptual mastery of work nor to the mastery of disturbance handling. In the regression analysis of the workers group, 72% of the variance of job satisfaction was explained by the mastery of disturbance handling, together with a positive appraisal of the challenges at work and an active outlook towards work development. Before the development program, another tendency was also noted. Low mastery of disturbance handling, good self-assessed qualifications and a positive appraisal of work were associated with fewer long-term stress reactions. The tendency to have an overly favourable view of one's social and intellectual skills has been shown in experimental studies with students (Kruger and Dunning 1999) and also among some other occupational groups in Finland (e.g., Keskinen 1990; Leino 1993). This phenomenon is related to the concept of "skilled incompetence" introduced by Argyris (1992). However, the tendency to overestimate or underestimate one's qualifications diminished during the development program. The appraisals of one's qualifications became more realistic. The development program seemed to reorganize the assessment basis of the subjects, especially in terms of their actual qualifications and of their subjective appraisal. The participants learned to assess the relations of their own competence and the requirements of the work process more precisely, indicating that their metacognitions of the work process had improved. The results further indicate that a realistic metacognition of the relations between one's work and mastering it can emerge in a situation where the enterprise, by organizing development programs and training, shows that mastering the work process is important. The connections between adequate mastery of the work process and job satisfaction also suggest that professional qualifications could be a source of positive well-being.

Outcomes at the Organizational Level

Reports of the outcomes of development programs at organizational level are rare. The second study presented in this article began when a considerable number of experienced paper makers went to work on a new production line and the productivity of the old production line declined. After the development program, those who stayed on the old line also a similar conceptual mastery than those who left for the new machine and participated in thorough training. The quantity and quality of the production on the old line also recovered from the decline. In current thinking, mastery of work or work-related knowledge is regarded as an inevitable prerequisite for organizational success (Nonaka and Takeuchi 1995; Hayes and Allinson 1998; Tsang 1997). Scientific knowledge of enhancing learning and of the formation of expertise in various contexts should also be used when trying to improve professional qualifications or the mastery of the work processes on the shop floor. The didactic principles applied in the development programs discussed in this article have become increasingly frequent in training practices at schools and at universities but are still rare on the shop floor. The application of these principles would, however, support organizational efforts to learn continuously from everyday work.

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RÉSUMÉ

L'amélioration de la maîtrise du travail et le développement des processus de travail dans les papeteries

Les machines de fabrication du papier sont les plus grandes installations de production en continu au monde et la fabrication de la pâte, en tant que processus de travail, est particulièrement complexe. Le processus de fabrication du papier étant rapide, les conséquences des modifications apportées dans le premier temps de fabrication (partie humide de la machine), notamment au niveau de la concentration de la masse ou du réglage de la tête de la machine, n'apparaissent souvent que dans les paramètres de qualité du papier parvenus dans la « partie sèche » de la machine. Par conséquent, la fabrication du papier ne repose pas sur un ouvrier isolé, mais bien sur un groupe d'ouvriers. Tous ceux qui travaillent sur une machine et qui surveillent le processus au moyen des dispositifs informatiques du système de fonctionnement automatisé doivent émettre des hypothèses quant à l'état du processus et des actions à entreprendre. Ils doivent également communiquer aux autres membres du groupe leurs observations, leurs actions ou leurs décisions. Les retards sont fréquents et à l'occasion, il peut s'écouler plusieurs heures avant que les effets d'une modification dans les paramètres se manifestent. Les équipes doivent donc pouvoir compter sur des moyens efficaces pour se transmettre l'information et, conséquemment, avoir une même compréhension des concepts de la fabrication du papier. Les pratiques visant à créer et à améliorer les compétences professionnelles dans les moulins à papier ont beaucoup changé et plusieurs problèmes associés à des pratiques de formation inadéquates ont été constatés.

Des programmes ont été élaborés dans le but de supporter l'amélioration de la maîtrise du processus de travail des ouvriers et de permettre le développement du processus de travail lui-même. Jusqu'à maintenant, la méthodologie a été appliquée sur environ 15 des 100 machines de fabrication du papier en Finlande. Les programmes de développement sont basés sur l'analyse des processus de production et du travail. L'analyse de ces processus nécessite la prise en compte des éléments de l'activité humaine au travail, des outils et de la division du travail. De plus, les modes d'action de l'équipe de travail dans différentes situations, la coopération des sujets à l'intérieur du processus de travail et des tâches y étant associées comme la maintenance ou le contrôle de la qualité sont également analysés. Pour y arriver, les chercheurs définissent des catégories ou identifient des questions clés en construisant des modèles. Ces catégories sont basées sur des analyses préliminaires du processus de travail de même que sur des entrevues et des observations avec le travailleur en activité.

Lors de l'élaboration du programme, les participants doivent procéder à une analyse approfondie des processus de production et du travail. Les équipes doivent verbaliser et élaborer les différents modèles pouvant rendre compte de chacune des parties constituant le procédé de travail. Au cours de ce processus, les équipes apprennent à utiliser les connaissances disponibles dans le groupe. Les compétences et l'expertise du directeur de la production, de l'ingénieur des procédés de travail, des experts des procédés chimiques, des experts des systèmes de fonctionnement automatisé des opérations et des agents de marketing peuvent également être sollicitées. Quatre sessions de deux jours sont nécessaires pour élaborer le programme. Chaque session doit être tenue deux fois afin de permettre la participation des représentants de tous les quarts de travail de l'organisation.

Les résultats des programmes de développement ont été évalués à plusieurs niveaux. La principale cible de ces programmes est d'améliorer la maîtrise conceptuelle du travail. Le premier niveau d'évaluation concerne l'apprentissage par la mesure de la maîtrise conceptuelle du travail et des perturbations possibles de même que le potentiel d'apprentissage que représentent les propositions de développement. Dans chaque programme de développement, plusieurs propositions de développement sont soulevées. Elles sont analysées en fonction des buts visés et du contenu du développement proposé.

Les connexions entre la maîtrise objective et subjective du travail, à savoir l'évaluation que les ouvriers font de leur travail et le bien-être exprimé, et leur développement durant le programme ont aussi été étudiés. Ces connexions sont utilisées pour évaluer les conséquences du programme de développement sur les métacognitions traitant avec les facteurs des réactions subjectives, comme la satisfaction ou le stress au travail.

Dans cet article, les résultats de deux études complémentaires concernant les programmes de développement sont abordés. Ils révèlent que la maîtrise conceptuelle du processus de fabrication du papier peut être considérablement améliorée à l'aide d'un programme de développement basé sur une analyse systématique et un modelage du processus de travail.

Les résultats indiquent également que l'analyse du processus actuel de travail est un moyen adéquat pour favoriser son développement. En effet, dans chacune des études considérées, plus de cent propositions ont été formulées pour améliorer le processus de travail. Les propositions de développement portent autant sur le développement technique que sur la coopération entre les différents groupes de professionnels. Elles touchent donc le processus de travail en entier. De plus, elles représentent les besoins actuels de développement dans le processus de travail, en plus d'être des sources d'information importantes pour débiter des actions de développement.

Les propositions de développement ont également été analysées du point de vue du potentiel d'apprentissage qu'elles représentent. La majorité des propositions visent essentiellement le développement du processus de production technique, c'est-à-dire une simple adaptation au contexte. De telles propositions représentent uniquement le niveau inférieur d'apprentissage. Cependant, les propositions visant à améliorer les modes d'action de l'équipe ou à augmenter la maîtrise cognitive du processus indiquent que les participants considèrent leur propre activité comme un objet de développement. Le besoin de comprendre le processus de travail et ses lois a clairement augmenté, démontrant ainsi une certaine augmentation de la motivation à travailler dans le nouveau contexte.

Cette étude a également voulu vérifier si le bien-être au travail nécessite des caractéristiques de travail positives ainsi qu'une bonne maîtrise conceptuelle du processus de travail. Les rapports présumés ont émergé seulement à la suite du programme de développement. En effet, après le programme, un haut niveau de maîtrise des perturbations pouvant survenir en cours de production a été associé à la satisfaction. Dans l'analyse de régression, 72 % de la variance de la satisfaction au travail était expliquée par la maîtrise de ces perturbations de la production ainsi que par une évaluation positive du défi au travail et une attitude active face au développement du travail. Le programme de développement a semblé réorganiser les bases d'évaluation des sujets, spécialement en regard avec leurs qualifications actuelles et leurs évaluations subjectives. Les participants ont appris à évaluer les relations entre leurs propres compétences et les besoins découlant du processus de travail, indiquant ainsi que leur métacognition du processus de travail se sont améliorées. L'émergence des connexions entre la maîtrise du processus de travail et la satisfaction suite au programme suggère que les qualifications professionnelles peuvent être une source de bien-être dans une organisation qui accorde de l'importance aux compétences et qui le démontre notamment par l'adoption continue du développement du processus de travail et de la maîtrise de ce processus en tant que caractéristique organisationnelle.

Les résultats concernant les programmes de développement ou la formation au niveau organisationnel sont rares. La seconde étude considérée dans cet article se concentre sur les expériences de plusieurs fabricants de papier expérimentés devant maintenant travailler sur une nouvelle ligne de production compte tenu d'un déclin important de la productivité de la vieille ligne de production. Suite au programme, les ouvriers étant toujours affectés à la vieille ligne de production possédaient une maîtrise conceptuelle similaire à ceux qui ont été affectés à la nouvelle ligne de production et qui ont participé à une formation. De plus, la quantité et la qualité de la production sur la vieille ligne se sont grandement améliorées. De nos

jours, la maîtrise du travail ou encore les connaissances reliées au travail sont considérées comme des préalables nécessaires au succès organisationnel. Les principes didactiques appliqués dans les programmes de développement sont devenus de plus en plus fréquents dans les pratiques de formation dans les écoles et dans les universités, mais elles sont encore rares dans les ateliers. L'application de ces principes devrait cependant supporter les organisations dans leur apprentissage par leurs propres activités.