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The Double Path of Expansive Learning in Complex Socio-Technical Change Processes

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Abstract

The purpose of this article is to describe how expansive learning in organisations can become a resource for learning in a wider community of practice (CoP). The “developmental work research” approach (DWR) based on cultural historical activity theory (CHAT) is beneficial for analysing and interpreting the requirements in a field of action. Engeström’s specific form of “action research” focuses on expansive learning in activity systems. However, complex socio-technical change processes cannot be initiated and managed by the local community of practice alone. In order to establish the use of new tools, new methodologies or organisational solutions in a field of work, a double path of expansive learning is needed: Findings from the participative analysis and interpretation of contradictions in the local activity system have to be transferred to wider communities of practice. This paper illustrates a double path of expansive learning by presenting the experiences of research and development in machine and plant engineering companies in Germany. In the AQUIMO project, a project team has developed an adaptable software tool for multidisciplinary mechatronical engineering and created a related qualification program. The support from external social researchers has helped to initiate, disseminate and establish new ways to organise the division of labour in teams of engineers.

Introduction

Engineering is considered a motor of innovation in society. However, engineering itself is always on the move and is affected by change in everyday work processes. The research project AQUIMO developed an adaptable software tool for mechatronical engineering in companies that are engaged in machine and plant engineering and created a related qualification program. One basic assumption for research and development is that

engineering processes have to change in order to become more interdisciplinary. To achieve this goal, the AQUIMO project was supported by social research concerning the socio-ergonomic issues in interdisciplinary projects and communities. In the early stage of the project, the main question in social research was to investigate difficulties that emerge in interdisciplinary collaboration in the division of labour between mechanical, electronic and software engineering. These difficulties are thought of as representing specific requirements for the software tool and the qualification programme to be devised by the project. Later in the project, the implementation of the new software tool was reviewed, and the formation of a new mechatronical work team was accompanied by the social researchers.

A formative approach towards evaluation was chosen for the social research on collaboration in the interdisciplinary community of engineers. This approach was based on the cultural historical activity theory (CHAT) since, from a social research perspective, this form of action research matches well to the demands of an accompanying analysis of the technological development. By means of CHAT and action research, a multi-perspective view of the iterative development cycles within the project, as well as participation of all persons concerned, can be achieved, involving the practitioners in engineering as experts in their fields of work and providing a wide range of basic concepts. Thus, the approach offers an adequate theoretical and methodical background to facilitate change in engineering practice. This article illustrates how expansive learning in local activity systems can become a resource for change that is supported by a wider community of practice (CoP). This double path of expansive learning facilitates dissemination and recognition of new tools, new qualification programs or new organisational solutions in a field of work.

To begin with, the next part on communities of engineers covers both background and analytic approach within the AQUIMO project, including the most germane concepts of activity theory (CHAT) and development work research (DWR), as well as details on how we defined the double path of expansive learning. The third part of this paper presents the research approach based on the notion of triangulation in social research that leads from subjective views to reflection and learning in the local communities. The fourth part gives a description of how findings from the case studies in the local CoPs have initiated similar change processes in other companies. This paper concludes with a reflection on the experiences made with the double path of expansive learning.

Communities of Engineers: Focus on boundary crossing

The first section of this part gives a short overview on the background and purpose of the presented AQUIMO project and the way in which interdisciplinary boundary crossing should function. The germane concepts of CHAT and DWR are described in a second section. The third section focuses on the CoPs participating in the circle of expansive learning in the local work teams and the wider community of practice.

Changing Work in Engineering: From subsequent work processes to interdisciplinary work

Three medium-sized companies, leading providers for their specific market in machine and plant engineering, a software company and two university-level institutions participated in the AQUIMO project.

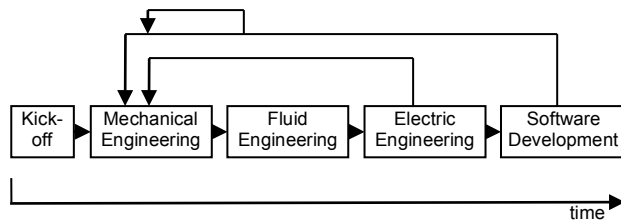


Figure 1: Current mechatronic engineering

engineering processes. The term “mechatronics” is a portmanteau word uniting mechanical and electronics engineering, thus representing the combination of mechanical engineering, electronic engineering, and information systems engineering. This combination of three engineering disciplines in an interdisciplinary design process aims at a higher functionality in technical systems (Bradley et al., 1991). The superior goal in the project is to replace subsequent or parallel processes in engineering that concentrate on either mechanical, electronic or software engineering by interdisciplinary processes. This interdisciplinary collaboration, taking place in communities of engineers from different disciplines, allows for the reduction of failure rates and for cost saving based on early design matching.

Despite the concept of mechatronic engineering combining mechanical, electronic and information systems engineering in an interdisciplinary design process, many companies still develop their products step-by-step. Usually, in a first step, mechanical engineers develop the physical parts of an engine. Planning the fluid mechanics may affect this physical engineering. Next, electrical and electronic engineers provide all electricity related components. Finally, software developers devise computer programs to control the functionalities of an engine. For this process, an initial kick-off meeting is often arranged to set the agenda and to align the team in respect to the requirements of the engineering project. However, while progressing from one step to another, there is only little, if any, communication between the engineering disciplines and since this communication is spontaneous, it is not systematically recorded and utilized. Especially when subsequent disciplines decide on indispensable modifications, or devise further enhancements which have an impact on previous stages of development, these previous processes have to be re-executed, as shown in figure 1. This insufficient collaboration results in long development times, high engineering costs and imperfect products (Würslin et al., 2007).

In order to enhance collaboration between engineers from different disciplines, those involved in an engineering project should work simultaneously on the same issues. This alignment has two facets: Firstly, there are interdisciplinary periods with a focus on design matching. Secondly, there are periods where the disciplines work parallel, yet connected. Interdisciplinary periods serve as synchronization points for the development of ideas, for decisions on alternatives and for the review of requirements, as shown in figure 2. This allows primarily for the reduction of time effort, thus meeting probably the most important factor in competition which is time to market. In addition, early design matching, a shared focus on requirements, and a reduced failure rate result in reducing the costs of both design process and production process. Last, but not least, ingenious mechatronic solutions for highly competitive products can only be reached through close integration of the different disciplines involved in the design process.

A reluctance to change current processes can be observed whenever practitioners are challenged by the reorganization of their workflows. Apart from general assumptions about employees’ resistance to change processes and workflows arising from issues of motivation, trust, uncertainty, or communication, the AQUIMO project identified one

The acronym AQUIMO is made up from the key words in the short description of the project’s objectives: Adaptable Modelling tool and QUAlification program for generating company-specific mechatronic

major obstacle for the implementation of interdisciplinary work: The different disciplines in mechatronic engineering use different notations to describe their view on the design of a product. While mechanical engineers are used to reading technical drawings both in 2D and specified projections of 3D, electrical and electronic engineers use circuit diagrams and wiring plans while software developers work with programme code and with a range of notations from UML (like class diagram, swim lane flowchart). Specific software tools, from CAD to integrated development environments (IDE) are used for these different formalized documentation methods. Originating from different engineering disciplines, these tools are usually not integrated and are therefore limited in interoperability.

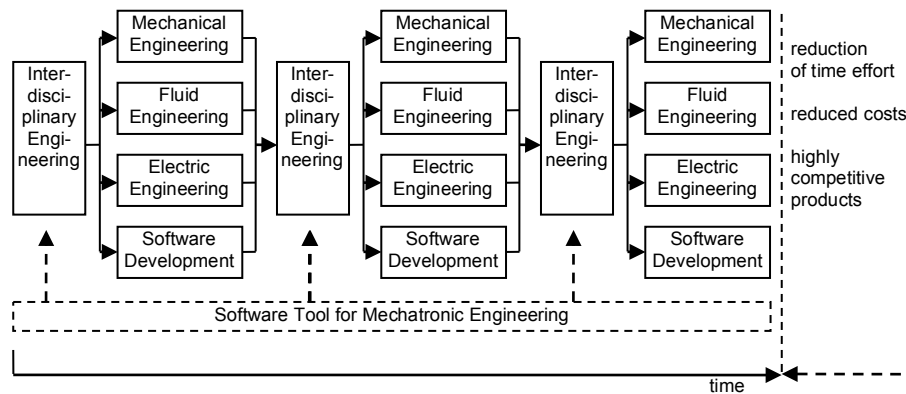


Figure 2: Interdisciplinary mechatronic engineering process

Starting from this point, a new software tool for mechatronic engineering was devised in a preceding project (Föderal, 2004). This tool allows a formal notation of all relevant data for mechatronic modules of an engine, i.e. all parameters that describe the properties of a component in an engine. Measurements, as well as functions, processes, constraints and other properties of a module in an engine are covered in a formal model that has to be devised for each distinctive class of components. Using the values within the parameters of this interdisciplinary model, discipline-specific technical documents can be generated automatically by specified transformations. These documents range from parts lists to template based technical drawings, using parametric solid modelling in CAD, and to generated source code for automated machine control.

The AQUIMO project sought to further develop this software tool. For this development, viewed from the perspective of the subsequent users, the requirements should be considered relative to the qualification of the user and a new methodology for interdisciplinary engineering.

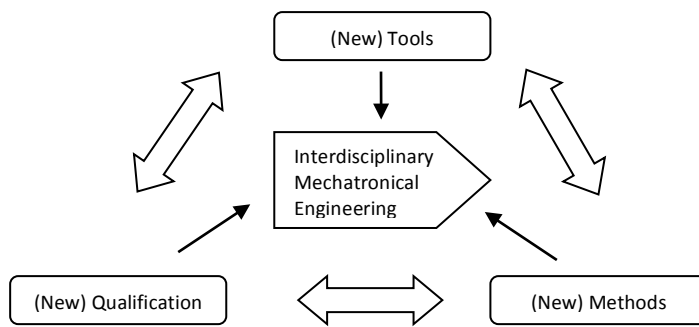


Figure 3: Aims of AQUIMO

In order to achieve these project objectives, social research investigated difficulties that emerge in interdisciplinary collaboration, using the formative approach of DWR within the community of engineers and in the project team, to support expansive learning about the social technical activity system of interdisciplinary engineering in these communities of practice.

Exploration of Activity Systems by means of DWR sensu Engeström

In his comprehensive work on CHAT, Yrjö Engeström (Engeström, 1987) outlines a research methodology for the exploration of activity systems. Here, he devises the DWR program connecting to the tradition of the action research. In this next section, the basic principles of DWR sensu Engeström will be described and the circle of expansive learning introduced.

First: Modelling and understanding activity systems, using a triangular structure, allow for the integration of an individual perspective with a social perspective, by relating to tools and signs, to artefacts, as well as to rules and division of labour. Key element in CHAT is the object of an activity, also identified as object or product of work. An object can be of a material or immaterial kind. In activity systems, participating practitioners refer to the object of the work by their agency in order to have an effect on the work object aiming at a specific outcome. According to Engeström, each activity system has exactly one object which defines the activity system through motivating structure and action within the activity system. Within an organisation such as a company, and also within sub-organisations such as work teams or departments, there are, typically, a number of different objects motivating structure and action, so that a number of activity systems can be examined. Different activity systems within an organisation influence one other and may even hinder one another. The analysis of neighbouring activity systems that are connected serves to uncover these different objects in order to identify causes for impediments, or to support the transformation of several activity systems into a common activity system.

In addition to the object of work, each activity system is comprised of subject, instruments, division of labour, community, and rules as defined elements. These elements of the activity system interact continuously, prompting and constructing one other, and they are affected by the cultural and historical background. For these elements and their relationships, a typical triangular structure can be devised, covering the facets of production, consumption, distribution, and exchange. This triangular structure serves as a

heuristic for the examination of activity systems, hence it can be applied in the study of collaborative work supported by computer systems (Kuutti, 1995).

In the course of DWR in the AQUIMO project, four elements are focused, as shown in figure 3 (Hackel, 2007):

- * Questions of qualification for the engineers involved address the individual subject.
- * Usability and utility of the software tool as well as of the discipline-specific notations concerning instruments within the activity system.
- * The shift towards interdisciplinary engineering, especially towards the usage of mechatronic components, can be explained in terms of separated or shared objects.
- * Issues of reorganising the design process relate closely to the division of labour within the activity system.

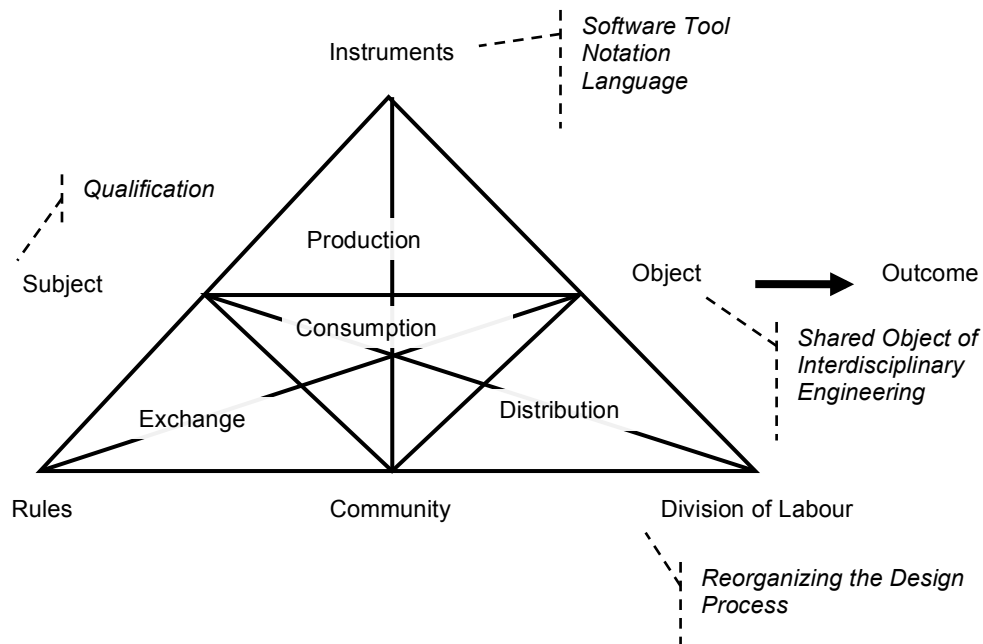


Figure 4: Focused elements of the activity system

Second: In activity systems, participating practitioners are considered to be experts in their field of action, as this is a basic assumption within the program of action research. Practitioners design their activity system, both actively and deliberately, within a continuous development system. In complex socio-technical change processes, assistance is needed from the wider CoP. This wider CoP supports the local practitioners to realise solutions and implement them in practice.

Third: Research in activity systems investigates contradictions within the field of practice. These contradictions in activity systems motivate and originate changes in an activity system and they become the starting point for the circle of expansive learning. The practitioners learn about the local contradictions of their work and identify and implement possible changes on the personal or organisational level.

DWR is akin to another educational approach called designed based research, which has become popular in recent years (Barab and Squire, 2004). Both approaches take an iterative path to come to new and innovative findings for specific research questions that arise in the field of application. Both are open to using various methods of social research. However, there is an inherent difference in the theoretical foundations: Engeström's approach is linked to the cultural-historical activity theory, hence explaining human activity by means of its orientation towards an object. Motives for action are central to developmental work research. Therefore, subjects within an activity system are considered as being the central agents of change and development. By contrast, design based research is aimed at the creation of new and innovative educational theories, placing the motives of the participants second in educational settings.

The next section describes how this circle of expansive learning is used as a double path of learning in different CoPs and which communities are involved.

The Double Path of Expansive Learning: From Local to Wider Communities of Practice

In the wider family of action research approaches, development work research is located near to the approaches of organizational development (Argyris and Schön, 1978) and action learning (Pedler and Burgoyne, 2008). They all focus on the real tasks and problems at work and help the participants proceed with them. Contrary to the traditional approaches of action learning in the UK (Revans, 1982), development work research, as it is described here, does not only give attention to small face-to-face groups but also to wider communities of practice. As Reason and Bradbury explicate (Reason and Bradbury, 2008), the range of proposition for action research spans first- to second- and third-person research in practice. In this way, experience, knowledge and research ascertained by action research, can be relevant for the individual, for the face-to-face inquiring group and for the wider community (Pedler and Burgoyne, 2008).

In the study discussed here, the local face-to-face groups in the participating companies were not only involved in changing their local activity system, they also took part in a broader discussion on changing work processes in engineering, fostered by new technologies. In this way, the concrete experiences of everyday interdisciplinary work become learning items for the wider CoP. In complex socio-technical change processes, a double path of learning could be identified in the circle of expansive learning. The first path described the well known circle of expansive learning which has been observed in several studies related to activity theory. The second path of learning took place in the wider CoPs and is not as common as the first, in the literature of activity theory. On this path, the data acquired from the local CoP becomes an important source of information. The wider CoP learns about the needs and habits of the subsequent users of socio-technical solutions. In this way, tools and qualification programs can be tailored to the requirements of later users and participants.

In activity theory, the circle of expansive learning is illustrated as in figure 6 below. This is how the local circle of expansive learning took place. The first path of expansive learning starts out by questioning established practices and then leads on to analysing the activity. The expansive modelling of a new solution is the heart of the circle. This solution is examined and implemented, and finally, the circle ends with the reflection on the new process and the consolidating of the new practice. In all of these states, contradictions can

become a learning item in different ways. The need state gives the impulse for further analysis as a primary contradiction. Secondary contradictions are double binds as initial points for designing new solutions. Later, when the new model is implemented, resistance becomes an expression for unsatisfactory solutions as tertiary contradictions. Quaternary contradictions finally show how the solution has to be inter-coordinated with the activity systems in the neighbourhood.

For the second path of expansive learning, the carefully obtained data from the first path become learning items for the wider community of practice. In the AQUIMO project, this led to the reflection and discussion of requirements as well as to the development of new tools and procedures for development and research in machine and plant engineering. The observation of contradictions which were caused by this implementation resulted in iterative changes of the solution. In figure 6, this path is indicated by the dotted arrows.

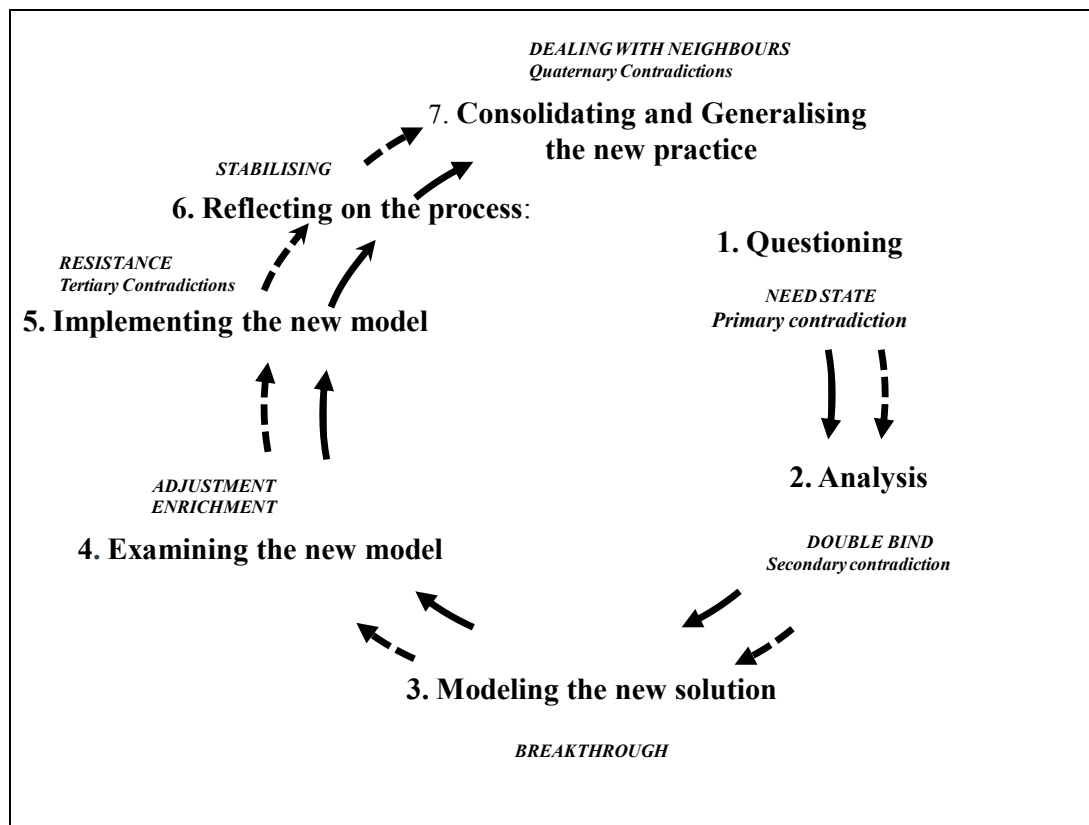


Figure 6: The double path of expansive learning

The reflection and discussion of the different aspects of the interdisciplinary work uncovered in the analysis of the local communities, initiated a deeper understanding of the activity system. The requirements of the field can be transferred and embedded in supporting solutions in the form of instruments, qualification programs or organisational change, not only for the specific local communities but also for other working groups in similar areas.

In order to achieve this transfer of new approaches in the mechatronical design process for the wider communities of practice, different CoPs participated in the AQUIMO project. Figure 7 shows which CoPs participated in this double path of learning as local, wider or intermediate CoPs.

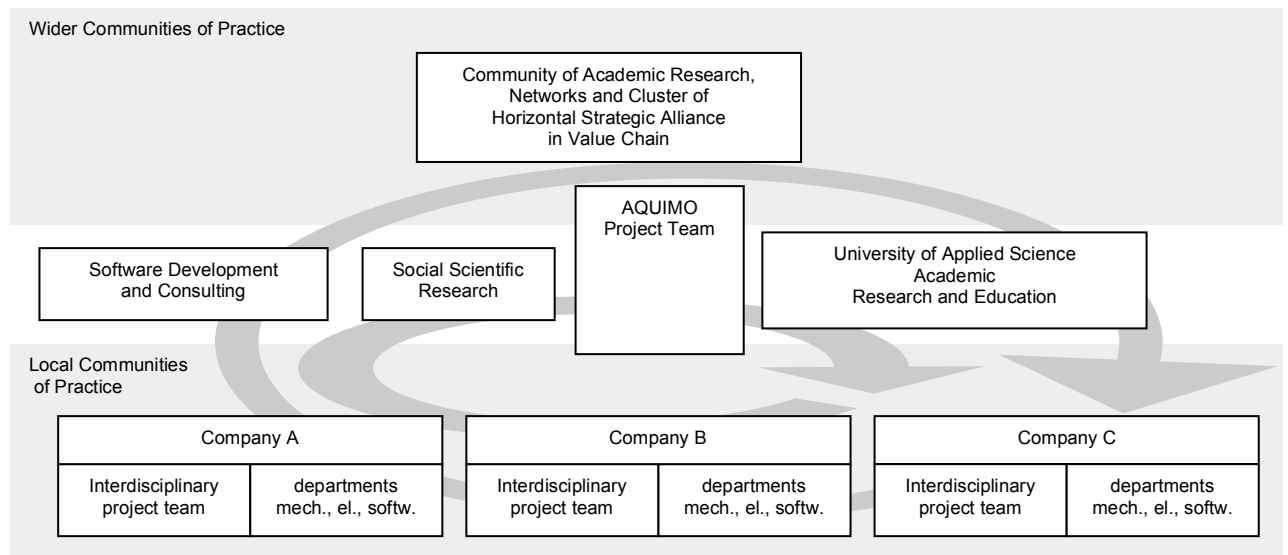


Figure 7 Communities participating in AQUIMO

The AQUIMO project connects a number of local and wider communities of practice. The local communities consist of interdisciplinary project teams from three machine and plant engineering companies, which work with different types of labour division and organisational structures. The wider CoP comprises the AQUIMO as a research and development project (R&D) with different communities participating, including the further community of interest in the academic field as well as in the clusters and networks of mechatronical engineering. Some of the central stakeholders in the project are involved at every level of these paths of expansive learning and thus play a key role in the project. The following list describes in detail the different communities involved.

1. Local Communities of Practice, within 3 companies
 - a. Interdisciplinary project teams in mechatronical engineering: The team members worked in different areas of engineering in the machine and plant industry. The observation of the different and common contradictions in these teams, and the solutions the practitioners found to solve their contradictions, built the core of the study.
 - b. Discipline-specific departments: The teams belonged to departments of engineering which organised their division of labour in different ways. At the beginning of the project, they all divided their work into discipline-specific departments. In all three companies, the mechanical engineering was in a separate department. However, in two of the companies, electrical engineering and software development worked together. Leading members of the engineering teams participated in the AQUIMO project team.
2. Wider Communities of Practice:
 - a. AQUIMO as a R&D project:
 - i. Software Development and Consulting: The initiator of the project was a software development company that was founded by two engineers

who were familiar with machine and plant engineering. They identified the need state of interdisciplinary work in machine and plant engineering. Besides the general project management, they were responsible for the tool development and the definition of the related consulting processes.

- ii. Academic Research and Education: From a University of Applied Science, professors and research assistants were engaged in the academic community and the network of mechatronic engineering. They gave support to the software developing process and were responsible for the design of the qualification program.
- iii. Social research by the authors of this article: The task of the social research team was to analyse the division of labour in the local CoPs and conduct accompanying research according to socio-ergonomic issues. Another task involved the support of the University of Applied Science in the design of the qualification program.

b. Further Communities of Practice:

- i. Academic research and education: The project team presented and discussed their project results at academic conferences thus sharing their knowledge in this field with the community of interest in mechatronic engineering.
- ii. Networks and cluster of horizontal strategic alliance in the value chain: The project results were presented and discussed at network and cluster meetings in the related CoPs which connect companies working on similar problems, for example, by the VDMA, i.e. the German Machine and Plant Engineering Association.

From subjective views to reflection and expansive learning in local communities

As mentioned above, contradictions are the signs of change demands in the middle of the DWR approach. The process of action research aims to unveil and illuminate them. In this way, contradictions become starting points for possible development of an activity system. Contradictions, observable as difficulties within an activity system, serve as important indicators for change potentials in the activity system and as a trigger for change processes. According to Engeström, double binds are the starting point for learning processes within activity systems. Engeström uses this term to describe “a social, societal, essential dilemma, which cannot be resolved through separate individual actions alone – but in which joint co-operative actions can push a historically new form of activity into emergence” (Engeström, 1987, p. 165). When a group, or parts of a group, realises the nature of the double bind in their activity, this specific form of contradiction then becomes the initial point of expansive learning. Social Research supports this by analysis and presentation based on the activity theoretical model, and thus becomes a mirror for the community of practice. In the second circle of expansive learning, both the contradictions and the lessons learned in the local communities of practice become learning items for the wider CoP. This is why the quality of the data collected in the local CoPs has an important impact on the two paths of expansive learning, and the methodology has to be designed

carefully. A detailed description of the research approach is given in the following subsections. The first subsection describes the conditions in the local CoPs and substantiates the triangulation of methods. The following subsections illustrate the path from subjective views to reflection and learning in the local communities. Some excerpts from the collected data illustrate how the data was used in the different project steps of the study.

Conditions and methods in the local community of practice

In order to examine activity systems in the AQUIMO project, theoretical considerations from CHAT, as well as practical requirements from the field, define methodological choices. As far as CHAT is concerned, the necessity to include practitioners in the data analysis deserves a particular mention, besides the provision for quality criteria of qualitative research, when it came to data collection and data evaluation. As to practical requirements originating from the field, firstly, the general objectives of research and development within the project in question have to be considered; secondly, the conditions amidst activity systems in real life work processes must be taken into consideration, in this case, especially the occupational situation of the test persons.

The ethnographic examination in this field of engineering practice was targeted at winning a very comprehensive overview of the interdisciplinary collaboration between the mechatronic disciplines and identifying difficulties in this area. The investigation of difficulties in interdisciplinary collaboration touches on a sensitive subject. Difficulties and problems in organizations are often a taboo topic (Greif et al., 2004) so that inquiries into these difficulties have to take place in an atmosphere of trust. In this situation, individual interviews are most appropriate. However, this investigation also addresses a group phenomenon. It appears that it is not sufficient only to interview practitioners individually. In order to arrive at more exact and reflected results, the group opinion within the community and the subjective single opinions given in an atmosphere of trust should be treated with equal importance. In conclusion, a suitable combination of individual and group interviews must be devised. The field for the examination in question consisted of the departments for research and development in three medium-sized enterprises. In departments for research and development, knowledge is of expected monetary value for the enterprise, and therefore communication in general is subject to confidentiality so that it is not easy to gain access to these sensitive areas. Therefore, trust is essential for cooperation between practitioners and the researcher. Connecting to familiar forms of communication is a good strategy to gain acceptance. Since engineering experts usually have rather a high workload, only few people are available for interviewing so that these practitioners' time should not be excessively taken up by the inquiries. Consequently, survey methods need to resemble common situations of communication and be time efficient. To enhance expansive learning in the local CoP, a methodical procedure has been devised consisting of individual guided interviews, the structuring of statements by means of concept maps (based on the Heidelberg structure formation technique, i.e. the Heidelberger Strukturlegetechnik, see below) and a group discussion. Figure 8 gives an overview of this methodic procedure. In order to secure an exhaustive analysis, both individual interviews and group discussion were audio recorded. All the tapes were transcribed in full and evaluated by means of content analysis. The data report of this analysis was discussed in the project team with reference to requirements for the tool, the qualification program and the engineering methodology. The triangulation of

different methods shaped a highly differentiated picture of the difficulties in interdisciplinary collaboration in mechatronical engineering.

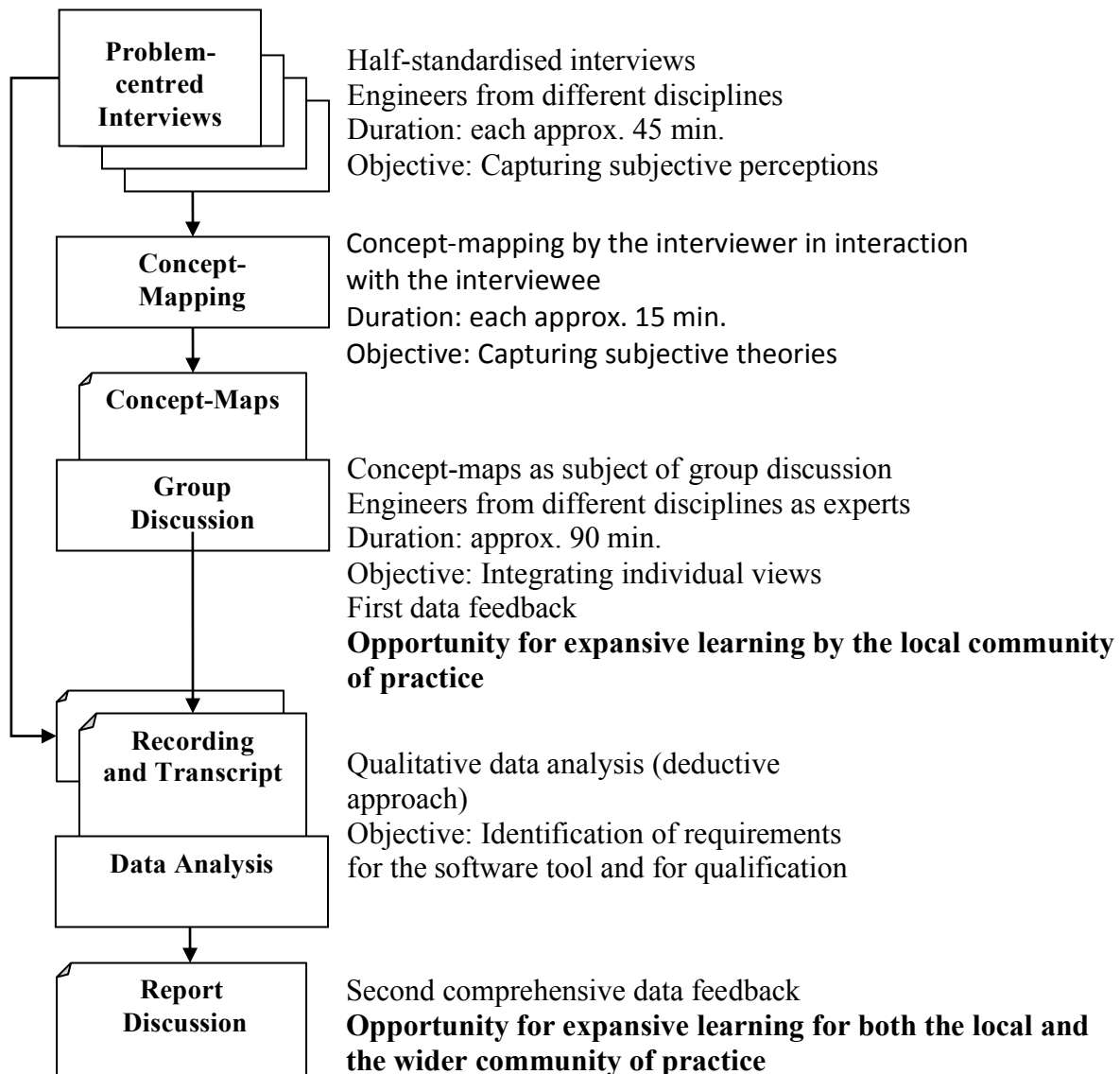


Figure 8 Overview of the Methodic Procedure

Subjective views: Problem-centred Interviews

In the first step, the individual views of the test persons are surveyed during guided interviews. The problem-centred interview (Witzel, 2000) leaves room for the test persons' subjective perceptions concerning the object of research, although specific topics are addressed by structured questions. Therefore, problem-centred interviews are apt to understand a problem from the view of the persons involved. Since the same questions are put to all interview partners, the comparability of the interviews is guaranteed. In addition, structured questions make sure that all relevant topics are dealt with. For the investigation in question, the following range of issues was considered as relevant, and therefore dealt with in the guidelines for the interview:

- * Introductory questions on the interviewee's basic personal data, his/her disciplinary background and his/her position in the hierarchy of the interdisciplinary team
- * Questions asking for the individual view on the object of the activity and in particular for the shared working task
- * Questions addressing the individual view on the interdisciplinary division of labour split into four main areas closely linked with one another i.e.
 - (a) allocation of duties and roles
 - (b) communication and divergence in knowledge
 - (c) trust within the collaboration and
 - (d) trust in the coordination of the shared work processes

These issues were articulated in such a way so as to offer an open frame for conversation and also challenge the identification of critical incidents. However, along with this, further questions, aimed at deepening the conversation, had already been fixed beforehand in order to fathom out the issues in the time available.

Beside questionnaire surveys, half-standardised interviews are probably one of the best-known forms of survey methods in social science, enjoying great acceptance. Normally, in this form of questioning, the test persons feel that they are being taken seriously. They perceive themselves recognised as being experts in their fields of work and are therefore willing to cooperate. Since confidentiality is assured beforehand, opportunity is given in the individual interview to raise issues which are not brought up in the group discussion. In our case, the problem-centred interview also served to prepare the practitioner intensively, regarding content, for later group discussion.

The following exemplary answers illustrate a differentiated individual vision of the shared object in collaboration, compared with a rather general statement. Both engineers worked in the same company and answered the same question¹:

Interviewer: *In which way would you describe the objective of your collaborative work in design? [...]*

Electronic engineer: *The goal? The goal? I wish the foundations of engineering would become integrated. At present, each discipline builds its own empire, the same with mechanical or electro-mechanical design or with software design; everyone has his own island he likes to live on. I see the risk where many colleagues design new things parallel to one another and, from my point of view, this shouldn't be. This knowledge pool should be distributed all over the department.*

Mechanical engineer: *The joint goal? Designing an engine that runs well.*

Reflection: Concept Maps

In the following step, these views were structured in the form of simple concept maps in order to create a base for reflection and consideration in the subsequent group discussion. Concept mapping is a special form of knowledge visualisation, arranging concepts and

¹ Translated from the transcript

their relationships. The Heidelberg structure formation technique (i.e. “Heidelberger Strukturlegetechnik, SLT” (Scheele and Groeben, 1984)) is well accepted as a method for gathering knowledge from test persons. This method, also known as Dialogue-Consensus Method (Dialog-Konsens-Verfahren) was developed in order to externalise subjective middle range theories (e.g. the examination of women’s everyday psychological theories about men or vice versa). A set of relevant terms for concepts in the subjective theories of test persons is connected with links. Each link represents one of a given set of relationships. The advantages of this method are (Bonato, 1990):

- * Visualisation: By visualisation of concepts and relations, the subjective theories of the interviewees can be made traceable in order to adequately comprehend associations of both concepts and relations.
- * Representation of relations: Relations between single concepts can be raised immediately. This determines whether a relationship between two concepts exists; in addition, this also reveals the type of relation. However, since the choice of relations is limited, the account of relationships is focused. A first advantage of this restriction is the prevention of excessive demands being made upon the test persons. A second advantage is that a comparison of different individual mental models becomes feasible.
- * Possibility of revision: Concept maps can be revised in parts or as a whole if, in the course of the interview, a test person advances a sufficient structure in knowledge concerning the object of research.

The term “concept map” usually denotes the graphic representation of individual cognitive structures or commonly shared concepts by externalizing them in the form of knowledge nets. In the past, a number of computer-based tools were developed in order to create and revise diagrams showing the relationships between concepts, thereby compiling knowledge structures. Computer support for the Heidelberg structure formation technique facilitates the documentation of the data and allows the visual or even graph-theoretical analysis of knowledge structures. A comparative analysis of concept maps allows the examination of differences between test persons referring to a specific knowledge domain. It also allows the examination of individual changes of the knowledge structures at repeated measuring times.

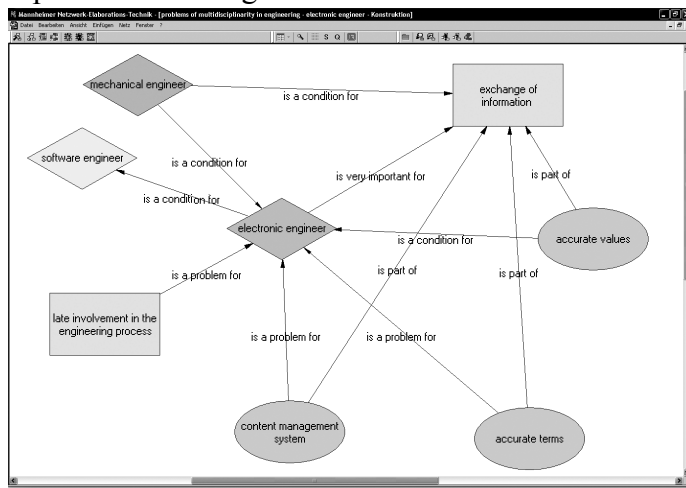


Figure 9: Exemplary Concept Map

For the examination in question, specific terms were written down denoting central concepts which were named during the problem-centred interview. Afterwards, the test persons were asked to connect them, using a few given relations. During preparation for the interviews, ten relations were fixed in view of the general objectives for the examination. This was carried out with consideration given to related research (e.g. (Scheele and Groeben, 1984); (Huss, 2003)). The chosen

relations cover logical relations (“is part of”, “is equivalent to”), conditions (e.g. “is a condition for”, “is aimed at”) and constraints (e.g. “is a problem for”, “is in low contrast to”). The computer-based tool of the network elaboration technique (Mannheimer-Netzwerk-Elaborations-Technik, MaNET (Eckert, 1998)) was used to support the creation and review of individual concept maps. All concept maps were printed for all participants in the group discussion thus serving as a starting point for the group process. The visual analysis of the concept map serves as an additional method during the final analysis of the collected data. Figure 9 shows an example of a concept map, created and reviewed during an individual interview².

Expansive Learning: Group Discussion

Group discussions are used as a surveying method if group dynamic itself is essential for the research question. The surveying method can then be considered as an “investigating group discussion”. In addition to an investigating group discussion, group discussions may serve to analyse and clarify group-specific behaviour patterns that lead to a shared group opinion. A cyclic interpretation of data with repeated data feedback for the participants may lead to causing changes in the opinions, attitudes, and behaviour of the test persons. This is called a “mediatoral group discussion”, changing the object of research by means of research, as it is significant for the program of action research (Lamnek, 2005). For the AQUIMO project, the group discussion pursued both functions:

- * On the one hand, a group discussion addresses the identification of further data by integrating individual views with a socially accepted common sense within the group concerning the issues of the examination, i.e. difficulties in the interdisciplinary collaboration in mechatronic engineering.
- * On the other hand, a group discussion also serves the purpose of fostering a change in the participant’s mental attitude, thereby facilitating perspective taking. Especially in interdisciplinary collaboration, this should enable insights into perceptions as well as into dependencies of the other disciplines, thus attaining new solutions for the activity system.

Both functions supported the local CoPs on their path of expansive learning. It is important to note the differentiation between group interviews and group discussions. In group interviews, the conversational principle of question and answer is transferred from questioning a single test person to a group of test persons. The group setting is considered to be stimulating for the participants. The answers given in group interviews may lead further than those given in individual interviews since each additional answer to a certain question is added to the answers already given by other participants in the group. Provided the interviewer acts as a proficient moderator, the interviewees tend to align their answers to socially accepted statements. This way, participants provide rather objective and accepted positions than single extreme opinions (Flick, 2006).

Unlike group interviews, group discussions as well as focus groups give special attention to interaction between participants. The conversational principle of question and answer between interviewer and interviewees is replaced by the concept of a conversation within the group of participants. While focus groups aim at resembling an everyday discourse on

² translated from an original map

a certain topic, group discussions are explicitly structured as a controversial dispute. Despite this distinguishing feature, group discussions as well as focus groups take advantage of group interaction, group process, and group dynamics, in order to produce data and, by immediate review, to interpret data. A group discussion is not only a discursive exchange of views and arguments; probable modification in the course of the discussion is significant for this surveying method. In most cases, the verbal interview is not (or to a limited extent) standardised, following a soft to neutral communication style (Lamnek, 2005).

In the AQUIMO project, the request to present and comment on the concept maps with the topic “difficulties in the interdisciplinary collaboration in the engineering process” achieved a high momentum in the group discussion. The presentation of individual concepts maps, one by one, followed by the invitation to comment on them, resulted in an open configuration of the discussion. In addition, the integration of individual views of the activity system resulted in perspective taking, giving rise to consideration of contradictions concerning the division of labour in the activity system. The outcome was unprompted suggestions for new solutions. At regular intervals, the participants in the discussion raised these issues of contradictions and alternative solutions.

The following extract³ from a group discussion is an example of perspective taking. While presenting his concept map, one electronic engineer addressed the problem of receiving information too late from the mechanical engineer. The mechanical engineer replied:

Mechanical engineer: *In development, there is often information one doesn't want to share too early, because there are too many issues in progress. You can see this in the example of the motor list. Something remains to be done. That means I would rather give ... I'll tell the current **development** status only when I have been asked. That means when I have not been asked, I stay quiet because otherwise this is wrong information.*

Interviewer: *It is an intermediate status, isn't it?*

Mechanical engineer: *Definitely, in this case. However, this is the current development status, you know? That would picture it. This would help some people. It is informative, sure!*

Electronic engineer: *You can put a notice on it: "preliminary"!*

Mechanical engineer: *Sure!*

Electronic engineer: *And if I only knew I was on your mailing list. There is nothing more I can expect from you. That is quite plain to me!*

This example may illustrate how the practitioners initiated the first change processes concerning their division of labour within the group discussion.

From local to wider communities

The second path of expansive learning was not structured by the triangulation of research methods. The social scientific researchers analysed all the data collected in the local communities of practice by structured content analysis based on the heuristic model of activity theory. A report based on this analysis was presented to the AQUIMO project team. The findings presented in this report strongly influenced the further development of

³ translated from the transcript

the project as a whole. Hence, expansive learning was facilitated beyond the local CoPs where the engineers who participated in the study learned about their contradictions, and thus discussed and implemented new ways to organise everyday work. The confrontation with the findings from the problem-centred interviews and the group discussion supported the project partners to create and improve the software tool for engineering, and to identify competency needs which are addressed by qualification (AQUIMO, 2010).

The reflection and discussion of the project results, in the wider CoP of machine and plant engineers, initiated similar change processes in other companies. In the following, we identified how the contradictions found in the case studies had been introduced as learning items for the different partners in the wider communities of practices. While the software tool, the related qualification program, and the notion of an interdisciplinary engineering methodology had been an attainment target for the AQUIMO project from the very beginning, the need for organisational change in the field of work emerged during the project.

The Qualification Program

Obviously, the qualification program that was devised by the AQUIMO project provides the most prominent resource for learning in the wider community of engineers. The qualification program was designed by the University of Applied Sciences that participated in the project. Students in mechatronical engineering study programmes get the opportunity to acquire knowledge and skills for interdisciplinary work, using the tool and the methodology developed within the AQUIMO project. Besides this next generation of engineers entering the activity systems in machine and plant engineering, professional engineers can engage in the qualification program for further training.

However, in addition to the obvious need for knowledge and skills, the findings from developmental work research in the local communities of engineers lead to increased consideration of the preconditions and benefits of interdisciplinarity in the qualification program. The related academic community of academic research in mechatronics recognised that the so-called “soft factors” have a significant impact in the engineering process. More specifically, the discussion of the results suggested that it is important to enhance the reflection according to the systemic linkages within the division of labour of different engineering disciplines.

In all three companies, the employees narrowly focused on their own disciplines. Tasks that were necessary for the product, but not meaningful for one’s own discipline, were regarded as side issues or even as a chore. The awareness of interdisciplinary collaboration was given, but had no priority. The discipline-specific tasks were regarded as being higher and more decisive compared with those of the other disciplines. Hence, different disciplines might well join forces in engineering; however, they still do not share a joint objective in their work. The desired shift towards interdisciplinary engineering still requires efforts to establish a shared objective of work.

Mechatrical engineering results in a division of work by type: Engineering activities are split up into tasks that are performed by different engineers according to their knowledge background (e.g. mechanics, electrical engineering, or software development). This division of work by type results in further specialization of the collaborating engineers. Engineers in different disciplines have discipline-specific knowledge and attitudes. But interdisciplinary mechatronical engineering relies on the exchange of problem statements,

ideas, solutions, and specifications between the involved disciplines. Therefore, a knowledge-based collaboration is only feasible if team members are capable of making assumptions on the knowledge and the motivation of their team members, thus basing their own work on this background. In the companies within the AQUIMO project, specific problems arise from the absence of, or insufficient capabilities in perspective taking. This is mainly a result of the differentiation of common and specialized knowledge.

The wider community learned that interdisciplinarity in engineering is affected by self-perception of the involved disciplines. Furthermore, it became apparent that perspective taking and a deeper understanding for the needs of the other disciplines were essential for an efficient design process. Hence, perspective taking, i.e. the capability to adopt other people's points of view, is an essential foundation for human communication and interaction.

As a result, the qualification program also included opportunities for perspective taking, inspired by intercultural training approaches. This outcome gained considerable attention and was also intensively discussed in the wider community of engineering.

The Software Tool

Besides the qualification program, the software tool developed within the AQUIMO project is another essential resource for learning in the wider community. The work of engineers is strongly affected by tools that allow them to handle the complexity of the engineering product. In the AQUIMO project, a shared software tool for modelling mechatronical components was considered the key approach towards a common understanding. The tool allows the formal description of machine components by relevant data in an interdisciplinary model. This interdisciplinary model comprises data from both mechanical and electrical engineering, as well as from software development. The software development and consulting company within the AQUIMO project aimed at fully developing this tool and distributing it as a product. Engineering teams can adapt this tool to their needs in order to use it for their work. More often than not, the introduction of the software tool is considered the starting point for a change in the engineering process. In order to introduce the software, both qualification and consulting become necessary.

In history, specialisation in engineering developed from the necessity to master complexity by focusing on single aspects of technical problems. This was accompanied by creating discipline-specific tools, methods and theoretical foundations. Nowadays, the main expected benefit of interdisciplinarity in engineering is overcoming the discipline-specific and thus restricted view regarding the product. However, in current engineering practice, an interdisciplinary shared object of work as the key element of the activity system is not easy to find. Discipline-specific tools, design languages and visualisations lead to different perceptions of the shared product and thus obstruct a systemic view.

The core task of the AQUIMO tool is to offer a common view on the shared aspects of machine components. In addition, the tool offers technical interfaces towards the specific tools of the three mechatronical disciplines. The findings from developmental work research in the local communities of engineers indicated requirements for the application of this basic principle in functionalities of the software tool. Advancements in usability and utility of the tool, which is considered as a shared instrument, may improve the quality of communication in engineering.

The Engineering Methodology

The qualification program and the software tool are visible and somehow tangible resources of learning for the wider community. Engineers may participate in the training or they may start using the software tool. However, the partners in the AQUIMO projects also devised rules, guidelines and blue-prints for interdisciplinary mechatronical engineering summing up to a methodology. This methodology has been compiled in the form of a handbook (AQUIMO, 2010), published by the VDMA, i.e. the German Machine and Plant Engineering Association. The handbook and its presentation in dissemination events is another way of learning in the wider community of engineering. Engineering teams may refer to this handbook when they shape their interdisciplinary design process.

In CHAT, terms and language are essential instruments for reference to the object of agency in an activity system. Different terms result in separate objects of activity and in separated activity systems. However, developmental work research in the local communities of engineers clearly showed that even shared terms, definitions, data and experimental knowledge do not necessarily provide a common ground for collaboration. In all three companies, the conflicting use of terms or language added to the difficulties of collaboration: The same terms were used from each discipline for different facts. Sometimes, different terms were used for the same facts. Of course, this impediment demonstrates, once more, the lack of a shared work objective.

The use of terms and language relates closely to the individual subject and is therefore an issue of qualification. Shared terms also establish the discipline-specific community. Related to this, interviews and group discussion identified a need to exchange domain-specific knowledge between the disciplines. This is the case especially when dealing with innovative problem domains that required new approaches.

The AQUIMO project team worked hard to define a common ground between the disciplines. Actually, in order to overcome misunderstandings between disciplines, neither a shared vocabulary nor a thesaurus were considered as a promising approach towards better communication and collaboration. The engineers in the project team addressed the problem of communication between the disciplines by employing rather abstract concepts: A modular system of building blocks for machine components was developed, based on the logics of object orientation in programming. The terms and definitions of object-oriented programming became an essential content in one of the modules of the qualification program. Furthermore, the AQUIMO software tool transferred the principles of object-oriented programming to machine and plant engineering.

Nevertheless, another contradiction occurred when the engineers of an interdisciplinary workgroup recognized that they had become isolated from the information flow of their basic discipline. The question remained as to how knowledge specific to one discipline could be obtained and utilised by several engineers from one discipline, spread across different interdisciplinary workgroups. Answers to this question have been found in the current sociological research on knowledge management (Porschen, 2008). Solutions for the design of knowledge management concerning tacit knowledge are mainly found by offering opportunities for social networking and communication. In this case, the local community of engineers directly addressed a question to the social scientific researcher to provide an intervention respective to this contradiction.

Organisational Change in the Field of Work

Besides qualification, tool and methodology, the findings from the developmental work research also suggested changing work processes directly in engineering. One company completely changed their way of working by establishing an interdisciplinary workgroup in order to improve the possibilities of perspective taking. A social researcher supervised the team's work. Since the company achieved the first positive results, the recordings of their experiences have made significant contributions to several group discussions within the project team. These were also presented at network events and conferences of the related disciplines. Hence, models for organisational structures lead to learning in the wider community.

One lesson learned in the local communities was the fact that the organisation of work, especially the division of labour in the local activity systems, has to be grounded on the shared object of mechatronical engineering. However, different disciplines have different goals which have to be aligned to facilitate an interdisciplinary design process. Where different solutions were discussed according to their advantages and disadvantages, the companies chose appropriate solutions, according to the issue in question, to solve their special contradictions.

It can be said that a lack in the flow of information was a common difficulty although informal teamwork was much appreciated in all the companies involved. Detailed information, such as specifications, calculations, or parameters either arrived too late, or not at all. Many appointments were made spontaneously and independently from the overall work organization of the companies. This meant that information relating to revisions on the shared artefacts was exchanged on an informal basis. There was no structured record of changes, and changes could not be tracked systematically. Often the reports did not give enough details, since a mutual understanding concerning specific details was not expected between the disciplines.

The mismatch between informal and detailed information was addressed by strengthening workspace awareness. This concept is considered as a part of group awareness which is an essential concept for coordinated collaboration that is based on shared artefacts. Gutwin & Greenberg (2002) have coined the term *workspace awareness* to sum up the need for the awareness which arises in small teams that operate in a shared workspace. They created a reference model by posing the important questions which typically need to be answered when a group of users interacts simultaneously in a shared workspace. This reference model clusters the questions into the three categories: who, what, and where. The most important questions for the companies in our study were particularly about "what someone else is working on" and "what has been changed recently". As a reason for the latter, we considered the fact that the three companies were not located far apart and there were only short distances between the engineers' workplaces. Consequently, a lot of informal teamwork occurred in all three companies, resulting in "local knowledge" within the work processes (Randell et al., 1995). This explained why other group awareness challenges like presence awareness, group structural awareness or emotional awareness, were not of central interest in our case studies.

The experiences in team organisation in the wider community led to a debate on the definition of an efficient flow of information. Local solutions offered the best practice examples in this discussion of the related networks and clusters.

Reflection

This article presents the theoretical and methodological background, along with central findings, concerning the social research in the AQUIMIO project. This research has investigated difficulties and contradictions of interdisciplinary collaboration in communities of engineers. Core task of the social research was to support and facilitate a change in engineering practice in machine and plant engineering companies. The aim of this article is to describe how expansive learning in organisations can become learning items for the wider community of practice (CoP) in order to establish new tools, new qualification programs or new organisational solutions in a field of work.

The devised methodology is based on central concepts of developmental work research as set forth by Engeström. Within this framework, this article illustrated the double path of expansive learning: from local to wider communities of practice. While the first path of expansive learning in local CoPs has been well established in several studies related to DWR, the second path of learning is not so commonly found in the literature on activity theory. Here, the wider CoPs learn about the needs and habits of practitioners. This leads to the start of similar change processes in other companies, and thus to the consolidation of new tools or organisational solutions within a field of work.

For a methodology in DWR, we showed how the combination of individual guided interviews and group discussion allows the survey of subjective perceptions as well as clarification, classification and reflection of the single perceptions, at group level. The carefully collected and analysed data become a rich ground for reflection and discussion in the related CoPs and thus enable the project partners to offer helpful implementations to the field of work.

The durable implementation of new ways of working and of new and enhanced tools in organizations depends on the wide acceptance by the practitioners. Action research approaches can support this process by adoption and appreciation (Dymek, 2008). In our study, expansive learning was supported in two ways: First, the social analysis and the mirroring of contradictions in their field of action led the local CoP to a deeper understanding concerning their own needs and difficulties, and marked specific points where the local division of labour had to change. Second, the wider CoP was sensitized to the initial situation and needs in the field of action. This enabled the project partners to choose among different options and pay attention to a holistic design considering the activity system. This initiated complex change processes in engineering practice.

One main question with regard to activity theoretical studies is the question of generalisation of the results. The paper gives an example of how case studies in local CoPs have become a resource for learning in the related communities thus enabling the scope of activity research to be extended. The role of social research in AQUIMO investigating interdisciplinary communities of engineers provides evidence for the potential of DWR. This form of action research matches well to the demand of an accompanying analysis of the technological development from the perspective of social research, facilitating as widely as possible the participation of the practitioners as experts in the research process. DWR effectively supports both groups of learners (the local and the wider CoPs) in finding solutions as new methods, instruments, changed organizational processes or qualification programs, by acting as an intermediary between the local requirements and the offers from related CoPs. In this way, both groups were accompanied on the double path of expansive learning.

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