Supporting Change through Expansive Learning in Engineering Practice

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ABSTRACT
Engineering is considered as a motor of innovaton in society. However, engineering itself is always on the move and affected by change in everyday work processes. This paper presents the ethnographic examination of activity systems in mechatronical engineering based on the approach of "developmental work research" as set forth by Engeström. Engeströms specific form of "action research" concentrates on activity systems. Contradictions and double binds force an activity system, the related community of practice and the practitioners themselves to change. They find and develop new ways to organize the division of labour and create new instruments to support this. Engeström calls this expansive learning. Difficulties in interdisciplinary collaboration in mechatronic engineering became the starting points for change in the here presented project AQUIMO. Expansive learning has been facilitated in two respects. On the one hand, the engineers who participated in the study learned about their contradictions in everyday work, and thus discussed and implemented new ways to organize their local community of practice. On the other hand, the confrontation with the findings from the studies supported the project partners to create an innovative mechatronical modelling tool and to identify competency needs, which are addressed by qualification.

Keywords
Interdisciplinary Communities in Engineering, Mechatronic Engineering, Activity Theory, Expansive Learning, Action Research, Triangulation of Qualitative Methods, Group Discussion, Concept Mapping

1. INTRODUCTION
The research project AQUIMO developed an adaptable modeling tool for mechatronic engineering in companies that are engaged in mechanical 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. In order to achieve this, the project AQUIMO was supported by social scientific 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 labor between mechanical, electronic and software engineering. These difficulties are thought of as representing specific requirements for the modeling tool and the qualification program to be devised by the project. Later in the project the implementation of a new computer based tool was reviewed and the formation of a new mechatronic work team was accompanied by the social researchers.

For the social scientific research on collaboration in the interdisciplinary community of engineers, a formative approach towards evaluation was chosen. This approach based on activity theory, since this form of action research is well matching the demand of an accompanying analysis of the technological development from the perspective of social research. By means of activity theory and action research a multi-perspective view of the iterative development cycles within the project can be attained, as well as participation of all persons concerned can be achieved, involving the practitioners in engineering as experts for their 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.

The next part on the theoretical foundations covers first both background and analytic approach within the project AQUIMO, second the basic concepts of developmental work research and third defines the requirements for an adequate research methodology. The third part of this paper presents the research methodology based on the notion of triangulation in social research and discussing advantages and critical points of the selected methods. For the fourth part findings are presented. A reflection of the advantages and challenges of supporting engineering practice by expansive learning concludes this paper.

2. THEORETICAL FOUNDATIONS
The first section of this part will give a short overview of both background and analytic approach within the project. The basic concepts of "developmental work research" as set forth by Engeström are described in a second section. Since the applica-

tion of research methods should be thoroughly considered, the requirements for a research methodology between activity theory and social practice in interdisciplinary communities of practice are focused in the third section, regarding both the expenditure and the options within the scope of the given resources.

2.1 Changing Work: From subsequent work processes to interdisciplinary work

Three medium-sized companies, leading providers for their specific market in mechanical and plant engineering, a software company and two university-level institutions were participating in the project AQUIMO. 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 engineering processes. The term "mechatronics" is a portmanteau word uniting mechanical and electronics engineering, hence 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 (1991). The superior goal in the project is to replace subsequent or parallel processes in engineering that are concentrating 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 an early design matching.

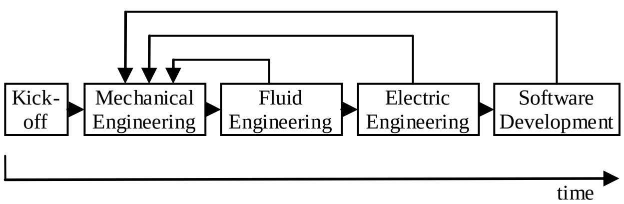

Figure 1. Current mechatronic engineering process

Despite the notion 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, mechanical engineers develop in a first step the physical parts of an engine. Planning the fluid mechanics may add to this physical engineering. Next, electrical and electronic engineers provide for all electricity related components. At last, software developers devise computer programs to control the functionalities of an engine. Often, an initial kickoff meeting is arranged to set the agenda for this process 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 communication between the engineering disciplines and, if any, this communication is spontaneous and hence not systematically recorded and utilized. Especially when subsequent disciplines decide on indispensable modifications or devise further enhancements, which have an impact on former stages of development, the 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 the involved engineers from different disciplines, they are supposed to work on the same issues in an engineering project at the same time. This alignment has two facets: At first, there are interdisciplinary periods with a focus on design matching. Second, 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, meeting the probably most important factor in competition, that is time to market. In addition, an early design matching, a shared focus on requirements, and a reduced failure rate result in reduced costs of both design process and production process. Last, but not least, ingenious mechatronic solutions for highly competitive products can only be reached by close integration of the different disciplines involved in the design process.

Whenever practitioners are challenged by the reorganization of their workflows, a reluctance to change current processes can be observed. Apart from general assumptions on employees' resistance to change processes and workflows arising from issues of motivation, trust, uncertainty, or communication the project AQUIMO identified one 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 read technical drawings both in 2D and specified projections of 3D, electrical and electronic engineers use circuit diagrams and wiring plans, and software developers work with program 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 usually are not integrated and are therefore limited in interoperability.

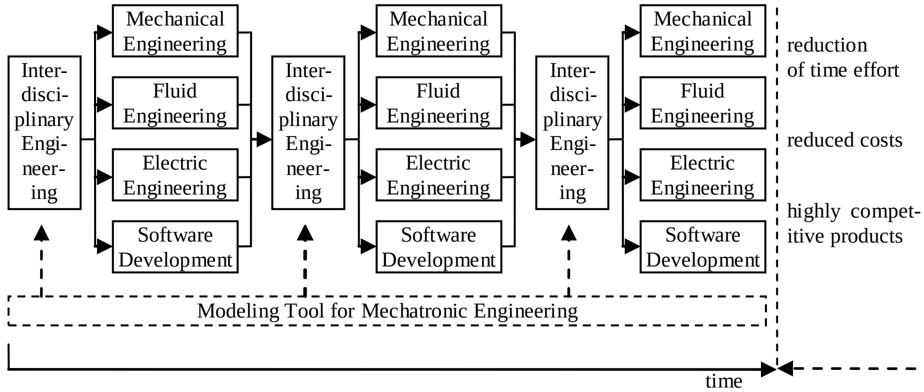

Figure 2. Interdisciplinary mechatronic engineering process

Starting from this point a new modeling 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 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 are ranging from parts lists to template based technical drawings using parametric solid modeling in CAD and to generated source code for automated machine control. Two major challenges arise from this notion of interdisciplinary engineering:

- Engineers have to design and describe parts of an engine at a rather abstract level of parameters, functions, processes, methods, etc., in order to capture the shared properties of a module relevant for all engineering disciplines.
- Engineers have to devise modules of an engine that are considered as mechatronic components, i.e. encapsulated systems with a functionality based on the integration of mechanics, electronics and software control. This leads to component-based engineering.

This way, a new modeling tool for mechatronic engineering enables and fosters interdisciplinary collaboration in a community of engineers. Of course, requirements that follow from the two named major challenges for both tool and practitioners are quite demanding. Therefore, the project AQUIMO sought to further develop the modeling tool considering the requirements viewed from the perspective of the subsequent users and aims to create a related qualification program. In order to achieve these project objectives, social research investigates difficulties that emerge in interdisciplinary collaboration, using a formative approach of developmental work research within the community of engineers.

2.2 Exploration of Activity Systems by means of Developmental Work Research sensu Engeström

In his comprehensive work on activity theory, Yrjö Engeström (Engeström, 1987) outlines a research methodology for the exploration of activity systems. Here, he devises the program of "developmental work research", connecting to the tradition of the action research. In the following three sections, the basic principles of developmental work research sensu Engeström will be described. First: Modeling and understanding activity systems using a triangular structure allows for integration of an individual perspective with a social perspective by relating to tools and signs, to artifacts as well as to rules and division of labor. Second: In activity systems, participating practitioners are considered as experts for their field of action, as it is a basic assumption within the program of action research. Practitioners design within a continuous development process their activity system both actively and deliberately. Third: Research in activity systems investigates contradictions within the field of practice. These contradictions in activity systems motivate and originate changes of an activity system. In a further section, consequences drawn from these three premises are considered as requirements for the research methodology of the here discussed research project.

2.2.1 The triangular structure of activity systems

Key element in activity theory 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 object of work 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 organization like a company as well as within sub-organizations like work teams or departments, typically there are a number of different objects motivating structure and action, hence a number of activity systems can be examined. Different activity systems within an organization influence each other and may even hinder themselves mutually. The analysis of neighboring 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 comprises subject, instruments, division of labor, community, and rules as defined elements. These elements of the activity system interact continuously, causing and constructing each other and 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 can be applied in the study of collaborative work supported by computer systems (Kuutti, 1995).

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

- Questions of qualification for the involved engineers address the individual subject.
- Usability and utility of the modeling tool as well as of the discipline-specific notations concern 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 reorganizing the design process relate closely to the division of labor within the activity system.

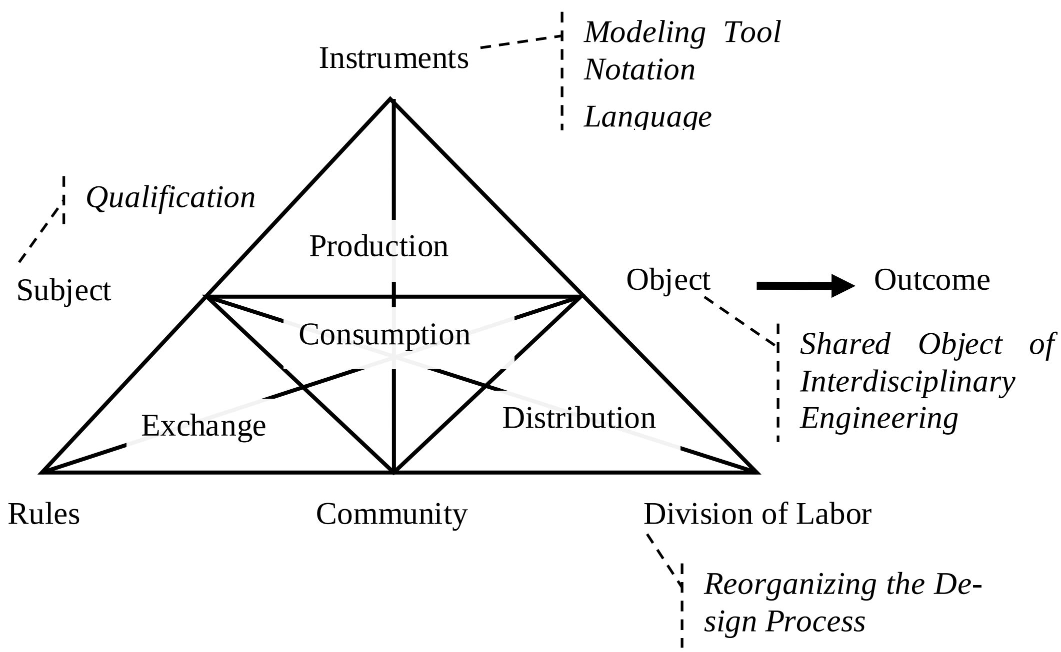

Figure 3 Focussed Elements of the Activity System

2.2.2 Individuals as experts for their field of action

By placing all participants in a project of social research, including practitioners (or test persons) from the field, in an active role within the research process, action research challenges basic assumptions of other paradigms in science. There, people and groups that are examined by scientists are objects of research, not subjects of research. In action research, discourse with people and within groups that are examined is essential for the acquisition and the validation of knowledge. This implies an effort in regular argumentation for validation and justification of the practical bearing of results in research. In this tradition, developmental work research as well gives special attention to the relationship of researchers and individuals in communities and groups being studied. Starting from the controversy over the Milgram obedience experiments (1963), a central point of the problems arising from the asymmetrical relationship between those who investigate and those who are investigated at first was analyzed in terms of an ethical responsibility of the researchers concerning participants in studies of the social research (Cieurzo and Keitel, 1999). In addition, it is not advised to disregard this relationship, since it can influence any process in social research and hence lead to false results. From these arguments, action research has devised the methodological requirement for a carefully reflected application of research methods and at least one data feedback to the participants in the field.

Arguing from these assumptions, developmental work research also aims at participation of the test persons in the research process as broad as possible. Test persons, i.e. practitioners from the field, are seen as subjects in the activity system. Therefore, participants in surveys and studies are regarded as both practitioners and experts in their field of practice. The researchers fulfill the tasks of moderating, mediating and advising. Through an inspection of the daily practice of communities and groups in relation to activity theory, the application of methods of social research reveals contradictions within an activity system or interactions between several activity systems. Social research holds a mirror up to the members of communities and groups in order to facilitate a continuous development process within the activity system both actively and deliberately by devising solutions for identified contradictions. Yrjö Engeström refers to this process of progress within an activity system with the term “learning by expansion” (Engeström, 1987).

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 it. Contrary to the traditional approaches of action learning in the UK (Revans, 1982) development work research does not only give attention to small face-to-face groups but to wider communities of practice as well. 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 that 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, local face-to-face groups in the participating companies are not only involved in changing their local activity system. They also take part in a broader discussion of changing work processes in engineering fostered by new technologies.

2.2.3 Contradictions as a starting point for expansive learning

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

Contradictions at different levels of an activity system are at the midst of developmental work research. The process of action research aims to unveil and illuminate them. 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, the starting point for learning processes within activity systems are Double binds. Engeström uses this term to describe “a social, societally, essential dilemma, which cannot be resolved through separate individual actions alone – but in which joint co-opperative actions can push a historically new form of activity into emergence.” When a group or parts of a group realize the nature of the Double bind in their activity, this specific form of contradiction 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.

2.3 Requirements for a research methodology between activity theory and social practice

In order to examine activity systems in the project AQUIMO, theoretical considerations from activity theory as well as practical requirements from the field define methodological choices. On the part of activity theory, the necessity to include practitioners in the data analysis deserves a particular mention, beside the provision for quality criteria of qualitative research addressing data collection and data evaluation. On the part of practical requirements’ origination from the field, firstly, the general objectives of research and development within the project in question are to be considered; secondly, the conditions in the midst of activity systems in real life work processes must be taken into consideration, here especially the occupational situation of the test persons.

2.3.1 General objectives for the examination

The ethnographic examination in this field of engineering practice was targeted on winning a very comprehensive overview about the interdisciplinary collaboration between the mechatronic disciplines and at identifying difficulties in this area. The results of this examination should have determined the requirements for the development of a shared tool for mechatronic engineering, for an interdisciplinary engineering process, and an adequate qualification program within the project from an ergonomic perspective. The investigation of difficulties in interdisciplinary collaboration touches a sensitive subject. Difficulties and problems in organizations are often a taboo topic (Greif et al., 2004). Therefore, inquiring these difficulties has to take place in an atmosphere of trust. Here, individual interviews are most appropriate. However, at the same time this investigation also addresses a group phenomenon. It does not appear sufficient to interrogate practitioners only individually. In order to come to more exact and reflected statements, the record of the group opinion within the community is of equal importance as the record of subjective single opinions in an atmosphere of trust. In conclusion, a suitable combination of individual and group interviews must be devised.

2.3.2 Requirements from the field concerning examination

The field for the examination in question consists of the departments for research and development in three medium-sized enterprises. Since in departments for research and development knowledge is of expected monetary value for the enterprise and therefore, communication in general is subject to confidentiality, it is not easy to gain access to these sensitive areas. Therefore, trust is essential for cooperation between practitioners and the researcher. A good strategy is to connect to familiar forms of communication, in order to obtain acceptance. Furthermore, workload of experts in the field of engineering is usually rather high. Hence, only few persons are available for the investigation. These practitioners should not be taken up excessively by the investigation. Consequently, survey methods have to resemble common situations of communication and have to be time efficient.

2.3.3 Conclusion: Requirements for a research methodology

The following requirements for the methodology arise from general objectives and the conditions in the field:

- The methodology should use a form of the data collection that is accepted by all involved persons in the research field.
- The test persons should only spend as little time as possible for the investigation.
- The methodology has to lead to informative results with the smallest number of test persons as possible.
- The methodology should allow the survey of subjective perceptions of difficulties in interdisciplinary collaborative while considering the sensitivity of the subject.
- Subjective perceptions should be treated in such a way that communication and reflection within the group is prepared.
- By means of reflecting relevant issues of interdisciplinary collaboration at group level, a clarification and classification of the single perceptions should be allowed regarding the whole context of interdisciplinary collaboration.
- The group should be sensitized for the need for changes in their collaborative work and should be supported to work on first options to change their local division of labour.
- The methodology should provide for quality criteria of qualitative research addressing data collection and data evaluation.

3. METHODOLOGY: FROM SUBJECTIVE VIEWS TO A COLLABORATIVE CHANGE PROCESS

The purpose of the investigation was to receive a most differentiated picture of the difficulties in the interdisciplinary collaboration and at the same to fulfill the named requirements from the field. For this purpose a methodic 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 4 gives an overview of this methodic procedure.

In the first step, the individual views of the test persons are surveyed during guided interviews. 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. We expect to gain additional knowledge from the group discussion for two reasons: On the one hand, we expect additional insights from the observation of emphasis weightings and changes within the single perceptions during the group discussion. On the other hand, we expect findings that arise from the discussion of the statements through considering and analyzing group dynamics. In order to provide for an exhaustive analysis, both individual interviews and the group discussion were audio recorded. All the tapes were transcribed in full and evaluated by means of content analysis.

For the investigation in question we chose a triangulation of different methods in the sense of a “between-method” approach. Different methods of interrogation addressing different research objectives were combined in order to get a highly differentiated picture of the difficulties in interdisciplinary collaboration in mechatronic engineering. The following three sections, which are addressing the guided interview, concept mapping and group discussion, give a comprehensive account on the single steps of the methodology.

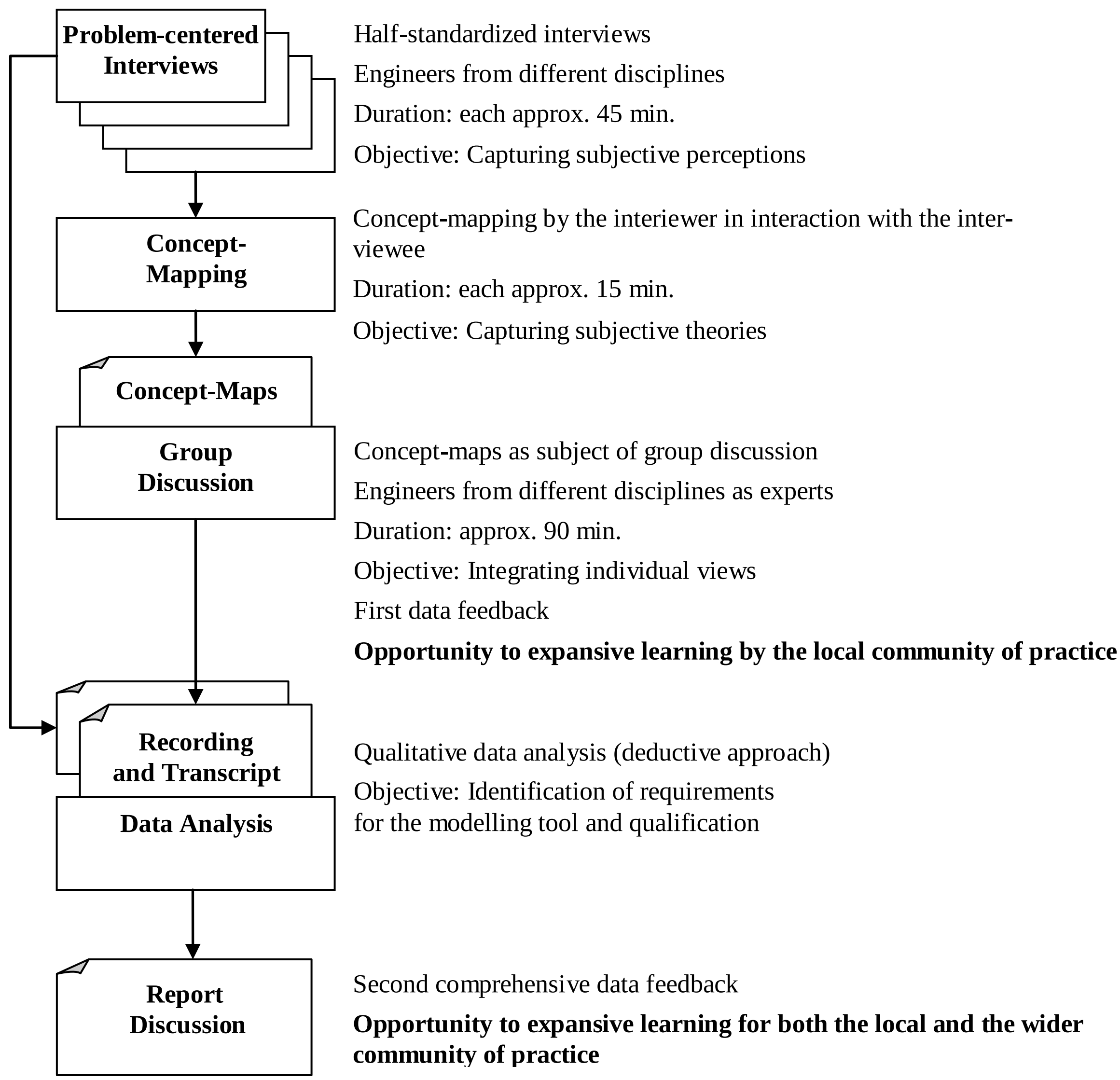

Figure 4 Overview of the Methodic Procedure

3.1 Capturing subjective perceptions in problem-centered interviews

The problem-centered interview (Witzel, 2000) leaves room for subjective perceptions of test persons concerning the object of research, although specific topics are addressed by structured questions. Therefore, problem-centered interviews are apt to understand a problem from the view of involved persons. Since the same questions are put to all interview partners, the comparability of the interviews is guaranteed. In addition, structured questions provide for the treatment of all relevant topics. The preparation of the questionnaire poses special requirements for the researcher and should always comprise an intensive review of theoretical foundations and the current research status. For the investigation in question the following range of issues were considered as relevant and therefore treated in the guidelines for the interview:

- Prefatory questions on basic personal data of the interviewee, his or her disciplinary background and his or her position in the hierarchy of the interdisciplinary team
- Questions asking for the individual view of the object of the activity and in particular for the shared working task
- Questions addressing the individual view of the interdisciplinary division of labor, split in for main areas linked narrowly with each other, 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 a way they offered an open conversation frame and challenged the identification of critical incidents. Along this, however, further questions for deepening the conversation were already fixed during preparation, in order to fathom out the issues in the available time.

Beside questionnaire surveys, half-standardized interviews are probably one of the best-known forms of survey methods in social science. The acceptance for this method is high. Normally, in this form of interrogation, the test persons feel that they are being taken seriously; and they perceive themselves recognized as experts for their working situation, and therefore are willing for cooperation. Since confidentiality is assured beforehand, the opportunity is given to raise issues in the individual interview which are not brought up in the group discussion. In our case, the problem-centered interview also served for the intensive preparation for the practitioner regarding content for the later group discussion.

The following exemplary answers illustrate a differentiated individual vision of the shared object in collaboration compared to a rather general statement. Both engineers are working in the same company and answered to the same question[1]:

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 that many colleagues design new things parallel 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.*

3.2 Capturing Subjective Theories by Concept Mapping

Concept mapping is a special form of knowledge visualization arranging concepts and their relationships. As a method for capturing knowledge of test persons, the Heidelberg structure formation technique (i.e. "Heidelberger Strukturlegetechnik, SLT" (Scheele and Groeben, 1984)) is well accepted. This method, also known as Dialogue-Consensus Method (Dialog-Konsens-Verfahren) was developed in order to externalize subjective middle range theories (e.g. the examination of everyday psychological theories of women about men or vice versa). A set of relevant terms for concepts in the subjective theories of test persons are connected with links representing one of a given set of relationships. The advantages of this method are (Bonato, 1990):

- Visualization: By visualization of concepts and relations, the subjective theories of the interviewees can be made traceable in order to comprehend associations adequately of both concepts and relations.
- Representation of relations: Relations between single concepts can be raised immediately. This determines whether a relationship between to concepts exists; in addition, this also reveals the sort of relation. However, since the choice of relations is limited, the account of relationships is focused. A first advantage of this restriction is to prevent excessive demands for the test persons. As a second advantage, a comparison of different individual mental models becomes feasible.
- Possibility of revision: Concept maps can be revised in parts or as a whole, if a test person advances a sufficient structure in knowledge in the course of the interview 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 order to create and revise diagrams showing the relationships among concepts, thus capturing knowledge structures, a number of computer-based tools were developed in the past. 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 as well as also the examination of individual changes of the knowledge structures at repeated measuring times.

[1] translated from the transcript

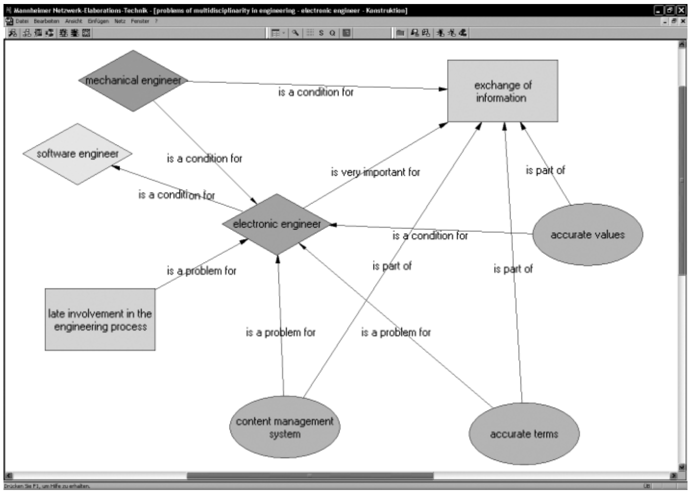

Figure 5 concept map

For the examination in question, specific terms denoting central concepts, which were named during the problem-centered interview, were written down. 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 happened with consideration of 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. In addition, the visual analysis of the concept map will serve as an additional method during the final analysis of the collected data. Figure 5 shows an example of a concept map created and reviewed during an individual interview[2].

3.3 Integrating Individual Views in a Group Discussion

There are different ways of collecting data in a group of test persons. In group interviews, the conversational principle of question and answer is transferred from interrogating a single test person to a group of test persons. The group setting is considered stimulating for the participants. Since each additional answer to a certain question adds to the former answers given by other participants, group interviews may lead beyond the answers of individual interviews. Hence, group interviews are accepted as a both efficient and effective method of data collection. Provided that 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 notion of a conversation within the group of participants. While focus groups aim to resemble an everyday discourse on a topic in question, 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; their 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 extend) standardized, following a soft to neutral communication style (Lamnek, 2005).

Group discussions are used as a surveying method, if group dynamic itself is essential for the research question. Then, the surveying method can be considered as an "investigating group discussion". In addition to an investigating group discussion, group discussions may serve in order to analyze and to clarify group specific patterns in behavior that lead to a shared group opinion. A cyclic interpretation of data with repeated data feedback for the participants may lead to cause changes in the opinions, attitudes, and behavior 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 examination in question, 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 to foster a mental change by the participants in order to facilitate perspective taking. Especially in interdisciplinary collaboration this is supposed to enable insights in perceptions of the other disciplines as well as in dependencies of the other disciplines and thus to attain new solutions for the activity system.

[2] translated from an original map

The request to present and comment on the concept maps concerning the topic "difficulties in the interdisciplinary collaboration in the engineering process" achieved a high momentum for the group process. The presentation of individual concepts maps one by one, which was 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, causing consideration of contradictions concerning the division of labor in the activity system and resulting in unprompted suggestions for new solutions. At regular intervals, the participants in the discussion raised these issues of contradictions and alternative solutions.

The following extract[3] from a group discussion is an example for 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 replies:

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 would only know I am 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 first change processes concerning their division of labor within the group discussion. In the course of the subsequent data analysis, this example substantiated the requirement of versioning with the option to mark provisional arrangements within the software tool. This proves that the range of proposition for action research reaches out from the individual subject to a face-to-face group and to the wider community.

4. RESULTS

The findings presented below influenced strongly the further development of the project as a whole. On the theoretical foundation of these findings, the involved practitioners can design actively and critically the activity systems of mechatronic engineering in the involved companies. In doing so, expansive learning was facilitated in two respects. On the one hand, the engineers who participated in the study learned about their contradictions in everyday work, and thus discussed and implemented new ways to organize their local community of practice. On the other hand, the confrontation with the findings from the studies supported the project partners to create an innovative mechatronical modelling tool and to identify competency needs, which are addressed by qualification (AQUIMO, 2010). The reflexion and discussion of the project results in the wider community of mechanical and plant engineers initiated similar change processes in other companies. In the following, some central findings of the social research according to the project AQUIMO were presented.

- **Discipline specific tools obstruct a systemic view regarding the product.** In history, development of science specialisation becomes necessary to master complexity by focussing single aspects concerning the topic of research. This was accompanied by creating tools, methods and theoretical foundations. Nowadays the main expected benefit of multidisciplinarity in engineering is the overcoming of the restricted discipline specific view regarding the product. 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 Work of engineers is strongly affected by tools to handle the complexity of the product. This finding confirms the necessity of a mechatronical software tool as it is developed in the project. The task of this tool is to offer a common view on the shared aspects of the object and to offer an interface to the specific tools of the three mechatronical disciplines.
- **Even shared terms, definitions, data and experimental knowledge do not necessarily provide a common ground for collaboration.** The conflicting use of terms or language adds to the difficulties of collaboration in all three companies. On the on hand, the same terms are used from each discipline for different facts. On the other hand, different terms are used for the same facts sometimes. Of course, this impediment represents once more the lack of a shared object of work. In activity theory, terms and language are essential instruments for the reference to the object of agency in an ac-

[3] translated from the transcript

tivity system. Different terms result in separate objects of activity, and in separated activity systems. In the project AQUIMO, a shared software tool for modeling mechatronic components by means of a formal notation of all relevant data in an interdisciplinary model is considered the key approach towards a common understanding. However, the use of terms and language relates closely to the individual subject and the discipline-specific community and is therefore an issue of qualification. A lack in the flow of information can be stated as another common difficulty. Detailed information, such as specifications, calculations, parameters, is arriving to late or not at all. Often the reports give not enough details, since a mutual understanding concerning specific details is not expected between the disciplines. These barriers in collaboration relate to both the instruments and the division of labor in the activity system. Advancements in usability and utility of the modeling tool, which is considered as a shared instrument, may improve the quality of communication. However, the workflow within the community relies on rules and a functional division of labor as well.

- **Perspective taking and deeper understanding for the needs of the other disciplines are essential for an efficient design process.** Mechatronical engineering results in a division of work by type: Engineering activities are split up in 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. Therefore, engineers in different disciplines have discipline-specific knowledge and attitudes. On the contrary, interdisciplinary mechatronical engineering relies on the exchange of problem statements, ideas, solutions, and specifications between the involved disciplines. However, a knowledge-based collaboration is only feasible, if team members are capable to make assumptions on the knowledge and the motivation of their team members and thus base their own work on this background. Hence, perspective taking, i.e. the capability to adopt other persons' points of view, is an essential foundation for human communication and interaction. In the companies within the AQUIMO project, specific problems arise from missing or insufficient capabilities in perspective taking. This is mainly a result of the differentiation of common and specialized knowledge. In the following, we describe in detail how these problems surface. In one of the companies the engineers in each discipline have only a vague idea of the importance of their work for the other disciplines to continue with their tasks at hand. Due to this, necessary information is often communicated too late. Due to a tight mode of collaboration and the importance of informal teamwork, all employees in the second company are aware of the information demands of the different disciplines in the everyday work processes. However, we still identified a need to exchange domain-specific knowledge between the disciplines. This is especially the case when dealing with innovative problem domains that required new approaches. In order to improve the possibilities of perspective taking, the third company completely changed their way of working by establishing an interdisciplinary workgroup. Thereby, the company achieved first positive results. Nevertheless, the question remained how knowledge specific to one discipline can be obtained and utilized for several engineers of one discipline across different interdisciplinary workgroups. Answers to this questions are found in the actually sociological research on knowledge management (Porschen, 2008). Hence solutions for the design of knowledge management concerning tacit knowledge are mainly found in offering opportunities for social networking and communication.

- **Workspace awareness is a central challenge for interdisciplinary engineering.** Group awareness is an essential concept for coordinated collaboration which is based on shared artifacts. For the companies in our study, especially workspace awareness is the central challenge for interdisciplinary collaboration. Gutwin & Greenberg (2002) have coined the term workspace awareness to sum up the need for awareness that arises in small teams that work 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 in a shared workspace at the same time. This reference model clusters the questions into the three categories: who, what, and where. For the companies in our study, particularly the questions "on what someone else is working on" as well as "what has been changed recently" occurred to be the most important ones. As reason for the latter we consider the fact that all three companies are not geographically distributed and that there are only short ways in between the engineers' workplaces. Due to this, in all three companies a lot of informal teamwork occurs, resulting in "local knowledge" within the work processes (Randell et al., 1995). Informal teamwork is appreciated much in all involved companies. As a result a lot of appointments are made spontaneously and independently from the overall work organization of the companies. However, this also means that a lot of information about revisions on the shared artifacts is exchanged informally. There is no structured record of changes and changes cannot be tracked systematically. This explains that other challenges of group awareness like presence awareness, group structural awareness or emotional awareness are not of central interest in our case studies.

- **Interdisciplinarity in engineering is affected by self-perception of the involved disciplines.** In all three companies the employees narrowly focus their own discipline. Tasks that are necessary for the product, but not reasonable for the own discipline, are regarded as side issues or even as a chore. The awareness of interdisciplinary collaboration is given, but has no priority. The discipline specific tasks are regarded higher and more decisive compared to those of the other disciplines. Hence, the different disciplines may well join forces in engineering; however, they still do not share a joint object in their work. The desired shift towards interdisciplinary engineering still requires efforts to establish a shared object of work.

The presented results show clearly the complexity of the change processes which were nessesary to support mechatronical engineering. This is the reason why practitioners of the local community of practice are not able to find sufficient solutions without support from the outside. There is a need of new methods, instruments and attitudes. In this way, developmental work research acts as intermediary between the local requirements and the offers from the related community of practice.

5. REFLECTION

This article presents the theoretical and methodological background and central findings concerning the social research of the Project AQUIMIO. It deals with the investigation of difficulties in interdisciplinary collaboration in communities of engineers. Core task of the social research was the support of the project partners by giving them an impression of their field of action from a social scientific point of view. This facilitates change in engineering practice of mechanical and plant engineering.

The devised methodology is based on central concepts of developmental work research as set forth by Engeström. It is combining individual guided interviews, the structuring of statements by means of concept maps and a group discussion. The realization of the suggested research methodology in three mechanical and plant engineering companies together with first substantial findings confirm the suitability with respect to the research objectives as well as to the basic conditions in the field. The methodology leads to informative results with a small number of practitioners, using a form of the data collection that is time efficient for the test persons and is well accepted in the research field. The combination of individual guided interviews and group discussion allows the survey of subjective perceptions as well as a clarification and classification of the single perceptions at group level regarding the whole context of interdisciplinary collaboration. Moreover, quality criteria of qualitative research addressing data collection and data evaluation are considered. Especially data feedback is substantiated in the group discussion and in the subsequent discussion of the findings with all partners involved in the project during regular project meetings. This validates and justifies the practical bearing of results in research on a regular basis. In order to examine best practice and lessons learned of interdisciplinary collaboration in communities of engineers supported by specific software tools and organizational factors, the methodology presented here was already employed for another investigation in a company outside the project AQUIMO.

The durable implementation of new ways of working and of new and enhanced software tools in organizations depends on the wide acceptance by the practitioners. Action research approaches can support this process in adoption and appreciation (Dymek, 2008). Expansive learning was supported in two ways: On the one hand, the social analysis and the mirroring of contradictions in their field of action led the local community of practice to a deeper understanding concerning their needs and difficulties and marked specific points where the local division of labor has to change. On the other hand, the wider community of practice was sensitized for the initial situation and the 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.

In sum, the role of social research in AQUIMO investigating interdisciplinary communities of engineers provides evidence for the potential of developmental work research. This form of action research is well matching the demand of an accompanying analysis of the technological development from the perspective of social research, facilitating the participation of the practitioners as experts in the research process as broad as possible. In this way, change was supported in engineering practice having regard to the needs of the practitioners in the field.

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