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THE INFLUENCE AND DEVELOPMENT OF SHARED MENTAL MODELS IN MULTIDISCIPLINARY PROJECT TEAMS

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ABSTRACT

Results of a study are reported that examined the link between group performance and shared mental models (SMM) in multidisciplinary project teams in the automobile industry. The focus of this paper is on the process of sharing during a situation of complex problem solving. This situation was created as a gaming simulation which was developed on the basis of the pre-analysed demands of 'real' project groups in design. According to a process-orientated multi-method-research design several methods, including a protocol analysis, were executed to detect patterns of communication as steps during the development of SMM. The results indicate that a shared understanding in groups is established either during preparation and explicit planning processes or as a consequence of critical incidents. These incidents force group members to communicate about their perspectives of the actual situation. Furthermore, evidence is given that the convergence of individual mental models concerning the process of group interaction and the skills and capacities of team members are more important in uncertain situations than the common understanding about task related aspects. The findings are discussed with respect to their implications on training and education of designers.

Keywords: Shared mental models; multidisciplinary design teams, critical incidents, communication

1 INTRODUCTION

Over the past decades the role of the designer has been changed from the individual inventor to a member of an interdisciplinary project group. This forces designers to understand the perspectives of their team-mates from other disciplines [1], [2], [3]. They have to install functional patterns of communication to combine the strengths of specialised team members and counterbalance their limitations. Therefore, the design process of a multidisciplinary project team is not just an accumulation of individual skills and knowledge. Moreover, team members have to interact and thereby align their mental models (MM) of relevant features of the task, the process of task accomplishment, and the individual capacities.

Most previous research on shared mental models (SMM) was dedicated to domains with structured tasks such as military combat [4], [5] or cockpit crew management [e.g. 6], whereas complex problems and ill-defined tasks like product development have just recently began to attract the attention of this strain of research [7]. As complex problems vary heavily from structured tasks, it is questionable whether the results of prior SMM-research can be applied to the more creative domain of design. Instead, analysing SMM within design tasks needs a different methodological approach that focuses on the process of product development [8]. A process orientated approach takes into account that in most cases there is neither the one best way nor the one best solution in designing [9].

Yet, it is not clear what kind of MM should be shared to solve complex problems like design tasks effectively [10]. A low degree of sharedness might lead to poor group coordination. On the other hand, highly similar or identical MM among team members could cause groupthink [11] which is characterised by striving for unanimity in the team and by the absence of divergent opinions and criticism. This might evoke cost-intensive failures if the SMM prove to be inaccurate. Although SMM develop during the interaction of the team members [12], it is not yet examined how a group should communicate in order to actively establish SMM.

2 BACKGROUND

2.1 Product development as complex problem solving in a social context

We define product development as complex problem solving in a social context. Product development is complex problem solving because designers have to deal with characteristics of complexity such as several interconnected variables, diverse and contradictory demands, high intransparency, uncertainty, and time pressure [13], [14], [15]. Thereby, product development does not only involve the cognitive process of the individual designer [9] but also motivational energy and the necessity to cope with emotions [1]. Reverses, mistakes and changing requirements may decrease the designers' feeling of self efficacy [16] which is the anticipation of one's own competence to succeed. A decrease or even loss of this feeling of competence will negatively affect the process of designing.

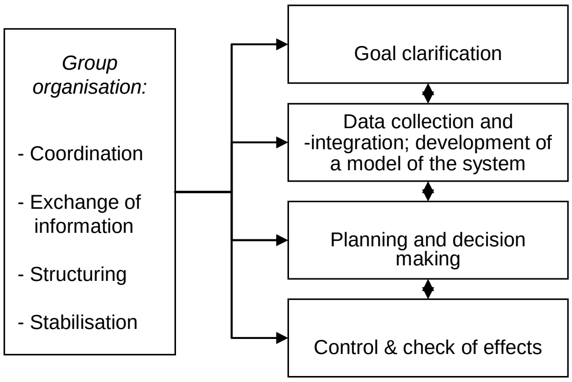

Figure 1. Stages of complex problem solving in a social context [18]

Due to their membership in project teams, designers are also confronted with motivation and emotions of the other team members, with different interests of the other disciplines that are involved in the project, and with situational constraints such as financial limitations [17]. For this reason, Badke-Schaub [18] stresses the importance of integrating the social context when analysing the process of product development. She draws on Dörner's research of human thinking processes during complex problem solving [15] and adds the demand of group organisation to the stages of action regulation [18]. In her model, task related problem solving (right section of Figure 1) alternates with activities to organise the group (left section). Group organisation comprises the coordination and the exchange of information between team members, the structuring of the group by determining roles and allocating responsibilities, and the stabilisation of the group. The latter includes conflict resolution and the establishment of a functional team atmosphere. Both task related activities and group organisation are highly interdependent requirements for designing in project teams (indicated by arrows in Figure 1).

Designing in team context is mainly about interlinking and exchanging information [19]. Therefore, the communication process of the project team has to be considered as basis of the analysis about the development of SMM. As there are no direct links to the mental models (MM) of the team-mates, communication – verbal and nonverbal – is the means for sharing MM. This raises the question how a functional pattern of communication may look like that could put forth an accurate SMM.

By analysing the content of communication of assigned student design groups, Stempfle and Badke-Schaub [20] detected functional differences in communication patterns which depended on various stages of problem solving. The authors distinguished routine from an elaborate form of problem solving. In routine problem solving the design students aimed for quick solutions that seemed to meet the demands. Solutions were generated and immediately evaluated without any deeper analysis. The solutions were accepted by the group when they exceeded some threshold of quality. This procedure saves time and effort, and enables the team to act fast on blurry information [21]. On the other hand, this modus operandi is also highly error-prone. An elaborated problem solving process comprises sequences of analysis of a generated solution, successive evaluation and re-analysis. The careful analysis of ideas enables a well-balanced evaluation. Thus, an immature decision could be avoided, although it is more time consuming. The concept of SMM might help to explain, when a group shifts from routine to elaborate problem solving.

2.2 Definition and types of SMM

SMM are conceived as knowledge representations in organised patterns about key issues of the team's reality. These patterns are shared by team members and enable them without explicit coordination to anticipate what their team-mates will do and need, and in consequence to adapt their behaviour [22], [23]. The term "shared" does not only refer to similarity between the MM of the team members. Instead, the construct includes also the overlap and complement of the individual MM [23], [12], [10], [7], so that the team can benefit from synergetic effects of dividing labour and consequently pooling the individual capacities [24]. This accounts especially for multidisciplinary project teams, in which specialised knowledge is held by the team members. To underscore these synergetic aspects of SMM the notion team mental models is often alternatively used [12]. As a related concept, transactive memory emphasises the benefits of distributed information, knowledge, and capacities in teams [25]. Transactive memory resembles a reference system that relates to the people who have specific knowledge. Thus, these people can be used as sources when their expertise becomes important for their team-mates' own work.

The broad SMM-subtypes task and team were differentiated by Cannon-Bowers, Salas and Converse [22] who proposed four categories of SMM: equipment model, task model, team interaction model, and team model. In our view, the equipment model is subsumable to the task model that relates as well to task procedures, strategies, and constraints as to likely contingencies and scenarios. The team interaction model (or process model) is supposed to include knowledge about responsibilities, interaction patterns, communication channels and information sources. The team model comprises knowledge about team members´ skills, knowledge, roles, preferences, and attitudes.

With exception of the equipment model we embrace the proposed submodels, but additionally assume a competence model. Thereby, we follow Peterson, Michell, Thompson, and Burr [26], who pointed out the importance of motivational aspects and their representation among team members. Their concept of collective efficacy is about the shared expectancy that the group will perform well on a particular task. In our view, the competence model comprises this feeling of self efficacy [27].

2.3 SMM and performance

Empirical evidence was reported in other domains that a high similarity of SMM positively affects team performance [28], [29] [30], [4], [5]. Studies that examined the influence of task and team orientated SMM found that task orientated SMM disclosed a stronger relationship with better performance than team orientated SMM [29], [4], [5]. To sum up the results, the impact of SMM similarity on performance seems to be task specific: SMM can inhibit as well as enhance group performance depending on factors such as complexity and divisibility of the task, on team maturity, status and knowledge diversity among team members, and on communication opportunities [31]. Several authors regard the accuracy of SMM as another central issue for the relation between SMM and performance [32], [5]. Convergence of the individual MM in team seems useless for performance if the uniform perspective is wrong. Besides similarity and accuracy, the quality of SMM depends on the centrality or importance of the SMM [7]. More important SMM might have a stronger influence on performance than secondary SMM [4], [7]. Cannon-Bowers et al. [22] assume that important models describe when and how team members must interact with each other in order to accomplish the task.

3 RESEARCH SET UP

3.1 Objectives

The study reported here was conducted in order to analyse the interrelation between group performance and SMM – concerning the common understanding of the task, the process of interacting, team members' skills and abilities, and the evaluation of self efficacy. The paper focuses on communication patterns within multidisciplinary project teams and shall provide deeper insights how communication progress relates to the establishment of SMM. In this vein, the question should be answered whether the whole group or just dyads of group members should work on identical MM.

3.2 Development of research instruments

The empirical study has been set up in three parts:

1) In the first part the demands of "real" project teams were analysed in order to understand the requirements of project teamwork in terms of task and process related SMM.

2) On the basis of the analysis, a gaming simulation for complex problem solving was created which served as an environment to examine communication patterns and development of SMM in groups.
3) In the main study, the influence of the communication progress and unfolding SMM on group performance was assessed with a sample of 24 designing engineers (12) and managers of R&D departments (12) of DaimlerChrysler in Ulm and Berlin, Germany, who acted in 8 teams in the gaming simulation.

Analysis of the demands of project teams

Plenty of SMM research was done on student groups [28], [29], [30] [24], [26], [4]. While students are a sample with whom laboratory studies are done easily, they are not representative for project teams in working life. In order to learn about the demands of project teams in industry, we interviewed 14 designing engineers and managers of R&D departments about impact factors on the work of multidisciplinary design teams at the DaimlerChrysler Research Centere in Ulm, Germany. The interviews were half-structured, each lasted about 1,5 hours. The participants were asked about general problems in collaboration with team members, system partners and clients, about constraints and about critical incidents [13] that affect the progress of the project, and the way participants dealt with. Further topics were causes of conflicts, decision making processes, complex problem solving in teams, and group organisation. The results of this interview-study were considered as domain specific requirements, which were incorporated into a gaming simulation of complex problem solving for groups, called DesertConstruction [33].

Creation of a research environment

The use of a gaming simulation as research instrument has several advantages compared to a field study. The gaming simulation constitutes a controlled research environment without reducing the complexity of reality as ordinary laboratory studies do. As extracted from the interview-study, the gaming simulation includes critical incidents, financial constraints, uncertainty, and time pressure as well as different goals and demands. It lasts two hours (without introduction) and is very challenging.
Each of the eight teams consisted of three members who were assigned to the roles of contractors in Libya. They had to deal with several individual projects simultaneously and also had to combine their resources into a consortium for jointly searching water reservoirs in the Sahara. DesertConstruction is simulating six gaming weeks. Demands are increasing after the first three weeks. Before a new week starts, the participants receive a currant account balance for both their own contractor company and for the consortium, thus the financial constraints of a real project team are represented.

3.3 Main study

By applying a multi-method-design, the main study assessed the relation between SMM and team performance, and analysed the sharing process in order to detect functional patterns of group communication.

SMM-score and performance

Conclusions on SMM were drawn in two different ways, in a collective and a holistic approach [32]. In the collective approach, the individual mental models of the team members were surveyed in a point of time and aggregated on team level by searching for similarities. For this purpose, we extracted a SMM-score on the basis of the participants' self-ratings of items related to the four assumed sub-models task (SMM_{task}), process of interaction ($SMM_{process}$), team (SMM_{team}), and competence ($SMM_{competence}$). A questionnaire was developed which included a total of 44 items such as "My group knows exactly which strategy will lead to success". The participants rated each item on a Likert-scale. The individual raw data were aggregated by applying the distance-ratio method [34]. By this method, a similarity-score for a team between 0.3 and 1.0 was computed comparing the ratings of every dyad of team members. This SMM-score was used to assess the impact of the convergence of the individual MM on group performance. The monetary results of the group in the gaming simulation were regarded as performance criterion. Correlations were calculated between SMM-scores and monetary results for the whole team (group level) and for each pair of group members (dyadic level).

Communication process

In the holistic approach [32] SMM emerge as a consequence of the interaction process in the course of time. Thus, the process of sharing individual thoughts and opinions during the simulation was examined. For this purpose, a case study design was conducted. The video recorded interactions of the group with the highest SMM-score (G1) and the group with the lowest SMM-score of the sample (G6) were evaluated using two different systems for protocol analysis: a descriptive observation system (DOS) [35] and the categorisation system for complex problem solving (KATKOMP) [20]. By comparing differences and similarities in the problem solving process of these two groups, hypotheses about the development of SMM were built up. The hypotheses were tested against the results of a third case (G7) which had been chosen because the group was one of two outliners. It had a high SMM-score but a low monetary result in DesertConstruction. Therefore, it did not support the assumption that high SMM will yield high performance.

On a concrete level, DOS is a systematic observation approach assessing behaviour of the group members that is relevant to the progress of team interaction and to team performance. It is structured in 42 well defined items that are related to five issues: group organisation, information management, goals and analysis, planning and decision making, control and reflection. DOS allows for depicting the specific situation when influential behaviour with respect to the stations of action regulation [15], [18] occurs. Scores were allocated in order to assess group performance for each of the five issues in DOS.

Table 1. Hierarchical structure of KATKOMP

Focus	Category
Content	Goal clarification (tz)
	Solution generation (ts)
	Analysis (ta)
	Evaluation (tb)
	Decision (te)
	Control (tk)
Process	Goal clarification (kz)
	Planning (kv)
	Analysis (kp)
	Evaluation (kb)
	Decision (ke)
	Control (ko)
Relationship	Management of relationship (bb)
	Expression of emotions (be)

On a more abstract level, each verbal contribution of a group member was analysed with KATKOMP according to its function. For this purpose, every single interact was classified in hierarchically structured categories. A interact is defined as a statement concerning a specific topic. Hence, a longer contribution of one person could be broken down into several interacts. On the highest level, KATKOMP distinguishes the three action foci content, process, and relationship orientated communication following the theoretical assumption that a project team does not only deal with the task itself but there is a need to organise the group process and to manage interpersonal relations (see Table 1). On the second level, each focus is subdivided. Both content and process focus contain a set of main categories which reflects the stages of action regulation [15] and design methodology [e.g. 36]. On a third level the main categories are elaborated by observational codes. We applied the software-tool INTERACT 7 (www.mangold.de) for coding.

The interrater reliability using KATKOMP was calculated for one time period. The congruence was κ=0,92 on the level of action foci. On the category level the interrater reliability resulted in κ =0,72 for task orientated categories, κ=0,75 for process orientated categories, and κ=0,28 for the very infrequent relationship orientated categories.

The frequencies of interacts were calculated for different time periods. Furthermore, the interacts were also used for a lag sequential analysis [37] in order to detect patterns in the communication process which could give a hint on the development of SMM. For this reason, the transitional probabilities between each pair of categories were computed and tested against the expected value that one category follows in group communication directly after a given.

4 RESULTS

4.1 Performance and SMM-Scores

Three out of eight groups managed a positive monetary result in the gaming simulation, five ended up with a negative account balance. Without taking any actions, the result in DesertConstruction had been -219.000 Libyan Dinars (LYD). Thus, one of the groups (G8, -288.663 LYD) would have been better off without its actual arrangements.

The overall SMM-scores of the teams averaged out at 0,75 (SD=0,07) [see 27]. The highest shared sub-model was SMM_{team} with a mean value of 0,78 (SD=0,08). G1 (0,84) had the highest aggregated SMM-score (SMM_{all}), G6 (0,61) the smallest.

As Table 2 illustrates, a significant positive correlation between SMM_{all} and the results in the gaming simulation as a measure of performance was only found on the dyadic level. On group level, the correlation was not significant (shortened with "n.s." in Table 2). The positive relation between performance and the dyadic SMM_{all} was solely backed by SMM_{team} and $SMM_{process}$, not by SMM_{task} and $SMM_{competence}$. Moreover, a significant increase of similarity over time was only noticeable on the dyadic level for SMM_{all} (T=2,8; df=23; p<0,05) and again for the sub-models SMM_{team} (T=3,3; df=23; p<0,01) and $SMM_{process}$ (T=1,9; df=23; p<0,05) – not for SMM_{task}.

Table 2. Correlations between SMM and performance on group and dyadic level

Level	SMM-Score	Correlation with performance
Group level	SMM_{all}	n.s.
Dyadic level	SMM_{all}	r=0,36*; p<0,05)
Dyadic level	SMM_{task}	n.s.
Dyadic level	$SMM_{process}$	r=0,38*; p<0,05)
Dyadic level	SMM_{team}	r=0,44*; p<0,05)
Dyadic level	$SMM_{competence}$	n.s.

4.2 Communication pattern and problem solving process

In order to gain insights into the relation of functional patterns of communication and the problem solving process, results from KATKOMP and DOS based analysis are presented. Patterns of communication were detected with a sequential analysis of the KATKOMP categories.

Analysis of KATKOMP categories

Roughly two third of the distribution of interacts in all three groups on the level of KATKOMP action foci dealt with content (*M*=62,2%; SD=7,0) whereas one third was dedicated to process orientated communication (*M*=30,4%; SD=4,7) and the management of relationship (*M*=4,6%; SD=2,1). Table 3 displays the distribution for each group separately. Both groups with high SMM-score (G1 and G7) had significantly higher communication rates than G6, the group with low SMM-score [see 27].

As in the study of Stempfle and Badke-Schaub [20], the distribution of interacts on the level of KATKOMP main categories was quite similar in the three groups with a medium correlation between these distributions of r=0.96. The most frequent categories were task and process orientated analyses of information (M_{ta}=33,8%, SD=5,9; M_{kp}=11,9%, SD=3,2). Almost half of the discussion was related to these two categories. Hardly any communication touched the setting of content or process orientated goals and the discussion about demands (tz, kz).

Table 3. Frequency of KATKOMP foci in the whole gaming simulation in %

KATKOMP foci	G1	G6	G7	Mean value	SD
Content	61,5	55,4	69,4	62,2	7,0
Process	31,6	34,4	25,3	30,4	4,7
Relationship	3,5	6,9	3,2	4,6	2,1
Overall interacts	*1389*	*985*	*1273*	*1216*	*208*

The three groups differed significantly in the frequencies of some KATKOMP main categories. These differences were proved with χ^2-tests and are marked by circles in Figure 2 (see Table 1 for explanation of abbreviations). G1 and G7 (both SMM↑) varied considerably from G6 (SMM↓) in the management of relationship (bb). The high amount of relationship orientated interacts in G6 was mainly due to one person who dominated the discussion and decisions of the group. His sarcastic jokes frustrated the other team members and impeded the collaboration (see the significant transition from process orientated analysis to relationship management in the state transition diagram in Figure 3).

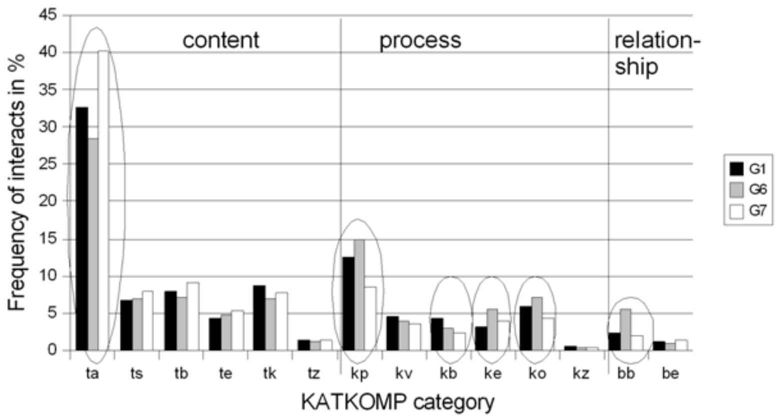

Figure 2. Overall frequency of KATKOMP main categories for G1, G6, and G7

Results of sequential analysis

The combined state transition diagram in Figure 3 illustrates patterns of communication for all three groups and depicts significantly frequent transitions with a basic rate higher than 0,01. The digits in front of the slashes indicate the transition probability, digits behind the slashes the basic rate.

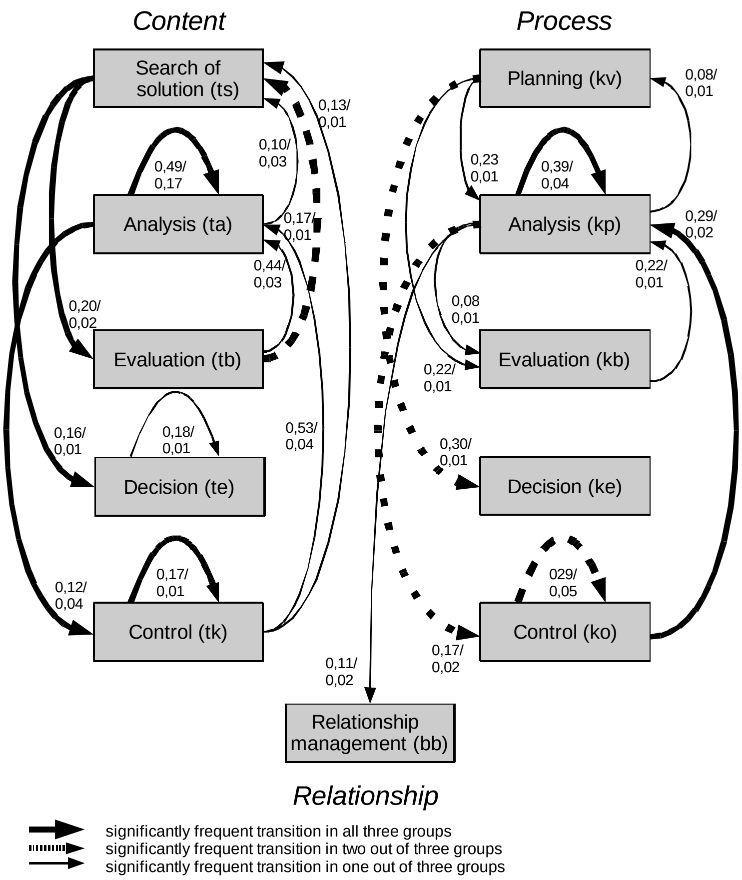

Figure 3. Combined state transition diagram of the case study groups G1, G6 and G7.

Results of descriptive observation systematic (DOS)

Focussing on the process of problem solving by applying DOS, two substantial differences in the proceeding of the case study groups became apparent: a) the reaction on the exposure to crisis and b) long-term planning. Figure 4 depicts the scores that were allocated in DOS for the problem solving performance of each group in every week of the six weeks of the gaming simulation.

a) Exposure to crisis

As the variances in the chart (Figure 4) imply, the groups exhibited different reactions on exposure to crisis. Whereas G6 and G7 (performance↓) merely reacted on the events without any preparation, G1 (SMM↑, performance↑) actively developed and adapted a strategy (high proportion of DOS-scores in the first four weeks). After serious problems in coordinating different projects in week 5, G1 managed the turnaround and performed better again in week 6 in all DOS-issues. In contrast, G7 (SMM↑, performance↓) perceived its accumulating problems in week 4 very late, then tried to work on a solution in week 4 and 5 (reflected by increasing scores in Figure 6), but settled on a wrong understanding of the situation by considering not all information at present. A tendency of groupthink [11] could be detected, because members of G7 strived for unanimity and thereby avoided to criticise each other. They did not engage in deeper analysis and neglected information that challenged their common view of the situation. Finally, G6 (SMM↓, performance↓) has had difficulties since the beginning due to the lack of motivation of one team member. The participants of G6 struggled only in week 2 and 5 seriously for functional group interaction. After failure, they gave up aiming for a common goal in the end of week 5. Instead, they just yielded for easier but less profitable individual projects. Thus, the tolerance for frustration was low.

b) Long-term planning

G1 (SMM↑, performance↑) was the only team that took time for long-term planning. Its group members broached the issue of goal contradictories and conflicting interests, and prioritised projects. In contrast, G6 and G7 (performance↓) started already in week 1 to prepare for the first low budget project in sight, although they could implement the measures not until the next week. G1 cared about its organisation such as the allocation of responsibilities and distribution of labour, whereas G6 and G7 acted in many tasks conjointly. Moreover, the participants of G1 were sensitive to ineffective group organisation and registered knowledge gaps already before negative consequences forced them to do. The groups also varied in the amount of information they regarded. G1 recognised crucial information that were distributed among its members, G6 and G7 (both performance↓) did not.

To sum up, differences between the groups existed in their scope of planning horizon, information management, group organisation, culture of interaction [27], motivation, and tolerance for frustration.

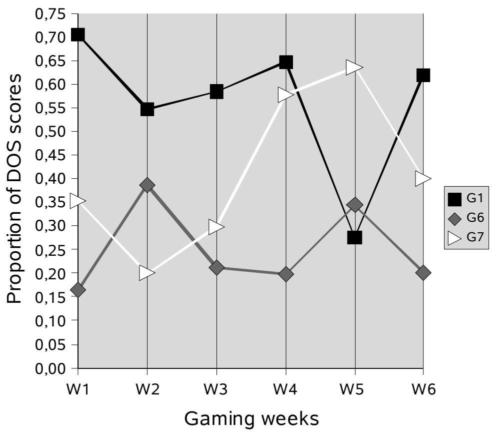

Figure 4. Assessment of the problem solving process with the descriptive observation system

5 DISCUSSION

Two aspects shall be highlighted in the discussion: the link between SMM and performance, and on the other hand the connection between long-term planning and the establishment of SMM.

5.1 SMM-score and performance

A major aim of this study was to examine the relation between the groups' SMM and their performance. Contrary to prior findings [29], [4], [5] our results showed evidence that team and process model (SMM_{team}/$SMM_{process}$) seemed more important to be shared than the task model (SMM_{task}). This conclusion is based on the significant correlation between dyadic SMM_{all} and performance which was only supported by SMM_{team} and $SMM_{process}$. The contradiction to previous results could be explained with characteristics of the task and the nature of the group structure. Whereas tasks such as military combat and crew resource managements draw heavily upon standard procedures and fixed roles and responsibilities, the complex problem solving environment DesertConstruction is characterised by uncertainty, different interests of group members, and the absence of standard procedures. In this way, it reflects the reality of multidisciplinary project teams in design. These teams are confronted with the necessity to develop new products, for which demands exist but no clear guidelines for the way to fulfil the demands – except for focussing on the creativity of the team members.

When experts work together, it is inevitable that they have to develop a similar comprehension on the way to proceed ($SMM_{process}$) rather than on the task itself, because labour is going to be distributed to the experts of the different disciplines in order to benefit from the synergetic capacities of the team. As a consequence of working on various subtasks, team members have to know about intersections in the process when the results of the subtasks are pooled. This knowledge is core element of $SMM_{process}$. On the other hand, a shared understanding of the team-mates' skills and capacities (SMM_{team}) seems to be important, because it enables team members to locate the specific knowledge in the project team. Hence, the owners of the knowledge could be contacted in case their expertise is needed. This mental reference to the owner of crucial knowledge is the essence of the concept of transactive memory [25] which we view as an integral part of SMM. Another reason why SMM_{team} is decisive for multidisciplinary project teams is the necessity to speak the same "language" and to be able to understand the perspectives of the other team-members

In our study, the synergetic aspect was backed by the finding that the relation between SMM and performance was only significant for dyads of group members but not for the whole group. This fact can be interpreted in the way that only the persons who conjointly work on subtasks should converge in their MM. Evidence for the importance of subgroups was also presented by Bierhals et al., [27] with the sequential analysis of the turn taking process in group discussion. Although a basic understanding of all team members seems to be helpful for group functioning, highly similar shared SMM are not a guarantee for good performance. As the case of G7 indicates, it might lead to the absence of criticism, and in consequence to false unanimity. Therefore, we assume that the impact of SMM similarity on performance could be described as curvilinear relation: too little convergence seems as counterproductive as too much similarity.

5.2 Communication pattern and problem solving

We attempted to gain insights in the development of SMM by analysing patterns of communication and problem solving of three case study groups. On a basic level of analysis it seems to be obvious that SMM are established by means of communication. The members of G6 (SMM$\downarrow$) discussed significantly less with each other than the participants of G1 and G7 (both SMM$\uparrow$). Further, interaction of this group was dominated mainly by one person. Thus, little opportunity was given in this group to share opinions and thereby to establish a common understanding.

In sum, the communication process of all three case study groups centred around the analysis of information. Beyond that not surprising result, the absence of explicit goal setting activities was striking. The groups might have disclaimed clarifying goals, because they thought they could rely on the global goals provided to them by the introduction. But the trust in global goals is precarious. Beyond the unanimity in abstract goals, the team members could differ on a concrete level without realising it. Therefore, global goals could cover subjacent goal contradictoriness and conflict of interests. Although the overall amount of goal related interacts were not higher in G1 (SMM$\uparrow$, performance↑), this group was the only one that addressed goal contradictoriness and conflicting interests and thereby developed a strategy for the advancement in the gaming simulation. Instead, the two other groups drew on the implicit assumption that all group members share the same goal.

With sequential analysis, patterns in the communication process were found in all case study-groups. It showed that the groups were engaged in longer sequences of information management as indicated by the significantly frequent transition within the KATKOMP category analysis. Further, analysis and control orientated interacts were significantly frequent related, which means that participants frequently double-checked information.

The only group that exhibited the elaborated form of problem solving [20] in process related communication was G1 (SMM↑, performance↑). This means that G1 frequently analysed its planning procedures before it evaluated the proposals and re-analysed the evaluation before a revision of the proposal was made. Due to these significantly frequent transitions between interacts concerning planning, analysis, and evaluation the process related proceeding was less susceptible to failure. G1 solely took the time to discuss its group organisation explicitly. This might be one reason for its high SMM-score and performance.

In content orientated communication, a pattern of problem solving was found in all groups that is similar to routine problem solving [20]. Thereby, the participants did not analyse proposals for solution but directly evaluated or decided to implement them. It might be due to time pressure that all groups applied the "quick but dirty-way" [21] of content related problem solving. Astonishingly, G6 (SMM↓, performance↓) exclusively exhibited significantly frequent transitions of interacts from evaluation to analysis on the one hand, and from analysis to the search for solution on the other hand. With these aspects of elaborated problem solving [20] the participants of G6 seemed to react on critical incidents. But as the analysis with DOS discovered, the group was lacking a functional interplay of its participants and did not work together as a team. Therefore, the content orientated transitions that accounted for elaborated problem solving had not any counterpart in process orientated communication. This might be the reason for the poor group performance and leads to the assumption that functional patterns which progress group organisation are more crucial to performance in highly uncertain, dynamic, and complex situations than functional patterns of task related communication.

On the basis of the observational data depicted with DOS, the conclusion can be drawn that SMM might develop in two ways – either as a reaction on critical incidents discussed by group members in order to solve actual problems or during long-term planning with the explicit discussion of group organisation. G6 and G7, the two groups with low results in the gaming simulation, practiced a strategy of muddling through until the demands have been increased so much that they were forced to act. Thus, the sharing of a common comprehension has been started not until critical incidents occurred. Before, participants of these groups did not take the time to discuss the initial information, but relied on implicit assumptions about task and group process. In contrast, members of G1 engaged in long-term planning und thereby interchanged their views of the situation and of group organisation. They were better prepared for the increasing demands than G6 and G7. As a consequence, it seems to be more effective to establish a shared understanding in the group explicitly during periods with lower workload than by mere reaction on critical incidents under high time pressure.

6 CONCLUSIONS

The results of this study have major implications on training and education of members of multidisciplinary design teams. It seems to be crucial to team performance that group members are not only skilled in task related aspects of their discipline but also in the way to organise and review group activities, as included in $SMM_{process}$. Especially the setting of process orientated goals should be improved. Moreover, participants of multidisciplinary teams must be sensitised that other team members have different perspectives of thinking due to the background of their disciplines. This understanding is decisive in order to gain a common "language" in a group of experts. Knowledge about skills and capacities of each team member (SMM_{teams}) ought to be shared in multidisciplinary teams, because this knowledge could serve as reference system when specialised knowledge is needed.

It must be granted that the results of this study are limited to self organising groups in complex situations. In contrast, autocratically leaded groups might be able to rely on the coordination done by the supervisor. The similarity of SMM concerning group organisation and process of interaction could be lower in these groups, because the shared understanding might be replaceable by the individual dispositions of the senior. Thus, further resarch on SMM should not only reflect on characteristics of the task but also of group structure and on the hierarchy within the group.

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