Chapter 10
An Observation-Based Method for Measuring the Sharedness of Mental Models in Teams

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Abstract This chapter explores the role and development of mental models in coordination. We introduce a theoretical framework on the development of shared mental models and a measurement approach based on observational data. The basic assumption is that individual mental models are shared through verbal communication. At the beginning of a task, this is likely to be explicit and thus observable. Once the team members assume that they hold a shared mental model, less verbal communication will be required and team members will continue their coordination in an implicit fashion. The methodology is illustrated using data from observations of two meetings of a design team. The analysis largely confirms our hypotheses. Implications for using the model and method in other contexts are discussed.

10.1 Introduction

This chapter aims to contribute to the conceptualisation of the measurement of sharedness, widely considered as one of the basic characteristics of team mental models that influence coordination (Cannon-Bowers et al. 1993; see also Chaps. 1, 2, 5, 7, and 11). Our framework addresses coordination as an activity in its social context, and team mental models as the corresponding cognitive representation. Coordination refers to a wide range of activities in different phases of aligning task

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or problem-solving processes, aiming to arrive at a desired goal (see Chap. 2 for an overview of the theory of coordination and Chap. 7 for conceptual and methodological approaches). Activities subsumed under coordination include impersonal coordination such as standardisation (van de Ven et al. 1976; Kieser and Kubicek 1992), standardised operating procedures, organisational rules (Grote et al. 2004), and personal coordination such as team interaction, negotiation, and mutual arrangements. Coordination can take explicit and implicit forms. The relevance and degree of explicit coordination depend on the complexity of the task, the distribution of knowledge and competencies of the persons involved, the history (both content and extent) of the team working together, the use of supporting tools, and the specific environment. Implicit coordination typically develops over time, and we argue that this process is enabled through the development of shared representations – also known as *shared mental models*.

We define coordination as planning and monitoring the process of problem solving in terms of task and team: who is going to work on what; which sub-task and when; delivering which output; and using what kind of equipment, tools, etc. The assumption is that explicit coordination activities lead to better performance due to the development of a shared understanding in the team (Stout et al. 1999; see also Chap. 11). Thus, effective coordination is based on the explication of mental models between team members regarding what needs to be done and how, sharing individual and discipline-oriented knowledge and procedures. Our approach to measuring coordination draws on these explications of mental models in verbal communication: Talking about the content of their mental models helps team members to achieve coordination; once shared mental models have been established, less discussion is required.

Numerous studies have analysed the influence of different coordination processes in teams on performance (e.g. Eccles and Tenenbaum 2004; Entin and Serfaty 1999; Espinosa et al. 2007; Hoegl and Gemuenden 2001; Orasanu 1994). Most of these studies found that effective coordination enhances team performance (Stewart 2006). Moreover, it has been shown in high-risk environments such as medical teams (Chap. 5), aviation (National Transportation Safety 1994), and the nuclear industry that deviations from procedural standards are the most frequent category in crew- or operator-related accidents. The results mentioned above indicate a causal relationship between coordination and shared mental models, as well as between shared mental models and group performance. In these studies, the range of behaviours in emergency situations was typically characterised as standard operating procedures with pre-defined steps that form shared rules to be followed by the team. Our question is, how can shared mental models in teams be measured in situations with less defined routines of behaviour and fewer standard operating procedures – what kind of coordination is relevant in these situations?

We postulate that explicit and implicit coordination are two forms of activities that occur in different phases of the problem-solving process. According to Wittenbaum et al. (1998), 'in-process planning may occur rarely without inducement because of the natural tendency to coordinate tacitly and task demands that make communication difficult while performing' (p. 199). Teams who have

worked together for a certain period of time develop shared mental models. On the basis of this common understanding, implicit coordination can evolve – which is advantageous in high-risk, time-pressure situations that require avoiding wasting time and/or concentration resources (Espinosa et al. 2004). The time and extent required for a team to develop shared mental models depends on the complexity of the task, the motivation of the team members to reach the common goal, the expectations of the team members derived from the history of the team, and the distribution of knowledge in the team (Arrow et al. 2000). Given the dynamic nature of team processes, it is of further interest to understand how sharedness develops over time and how exactly this process affects coordination and team performance. Little is known about how sharedness develops and how it affects the coordination process. This limited theoretical understanding and the small number of empirical studies to date could be due to the lack of convincing methods to measure these processes (Badke-Schaub et al. 2007). Further research is needed to arrive at more specific knowledge, but this requires better ways of measuring sharedness of team mental models in different situations and of assessing the development of sharedness all along the process.

In this chapter we want to address the following question: How do mental models in teams develop over time? How can we measure sharedness? How do changes in mental models affect the type of coordination? Do these phenomena concern the entire group, or are they mainly found in certain parts of the team?

10.2 Theoretical Framework of Sharedness, Mental Models, and Coordination

Any measurement must be based on an idea of what should be measured and how the measured variables are linked to each other. The measurement of sharedness also requires such a conceptual framework, which we present in the following subsection.

10.2.1 Concept of Mental Models

The concept of mental models was first proposed as an individual cognitive concept, defined as internal representations that humans build in order to cope with the world around them (Craik 1943; Gentner and Stevens 1983; Johnson-Laird 1980). While interacting with the environment, with other people, and with artefacts such as products, sketches, or prototypes, humans develop and adapt mental models (simplified representations) in order to understand, predict, and act in a world of continuously incoming and sometimes contradicting new information. Mental models include concepts, propositions, scripts, frames, and mental images.

These simplified representations enable a person to quickly assimilate fresh information and act even in new and unknown situations. Mental models are specific for a given task at a particular time, and change dynamically as they are updated with new information. As mental models are interpretations of reality, they can be more or less accurate and appropriate, and be more or less similar to other people's mental models. When individuals meet in a team context, these different mental models come together, ideally developing into shared mental models, which we will discuss in further detail ahead.

Shared mental models are defined as the degree of convergence among team members with regard to the content of known elements, as well as the structure between elements (Mohammed et al. 2000). They form an organised understanding of relevant knowledge that is shared by team members (Cannon-Bowers et al. 1993; Klimoski and Mohammed 1994). There are different assumptions about the various kinds of representations, yet most researchers agree on at least two basic types of representations (Cooke et al. 2000; Klimoski and Mohammed 1994; Rentsch and Hall 1994): Their definition of 'task mental model' encompasses all aspects related to the execution of the task, while the 'team mental model' is defined as all representations related to the team and the team members that are essential for working together. It has been shown that teams perform better when they have a shared mental model of the task (e.g. Lim and Klein 2006; Mathieu et al. 2005, 2008; Mesmer-Magnus and DeChurch 2009; Salas et al. 2008).

10.2.2 Types of Mental Models

In this section we introduce our theoretical framework of the development of shared mental models (see Fig. 10.1). The model builds on and further differentiates the distinction between taskwork and teamwork (Rousseau et al. 2006). This distinction explicates that taskwork includes working on the content and also managing the process, while teamwork refers to the coordination of roles and responsibilities in the team, as well as the creation and maintenance of a cohesive team climate. Thus, we differentiate among four types of mental models relating to the task, the process, the team, and the climate. For each type of mental model, we will spell out how explicit coordination can help to arrive at a shared mental model, and how these shared mental models in turn affect coordination processes.

The *task model construct* of Fig. 10.1 refers to representations of the problem at hand. Communicating about task-related content such as defining the problem, generating ideas, evaluating solutions, and making decisions should enhance the team's sharedness of the task mental model. The communication in the team gives further information about discrepancies in task-related knowledge between the team members. For example, explanations and questions are of particular interest, as they serve as indicators for missing knowledge: Team members provide each other with explanations or they elicit information often based on specialised expert knowledge about a subject held by team members. By asking questions and

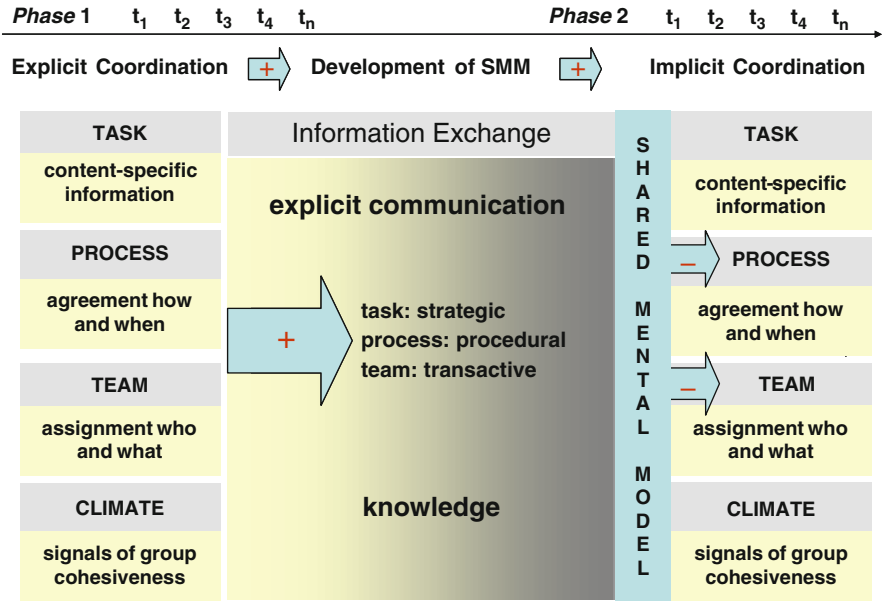

Fig. 10.1 A model of the development of shared mental models in teams. +: increases, −: decreases

providing information, the team creates a common knowledge base. The literature cited above on shared mental models contends that the more information that is exchanged, the richer the sharedness between the mental models of all team members about the task will be.

The *process model construct* of Fig. 10.1 refers to assumptions about the proper procedure for solving the task. We propose that in order to arrive at a successful outcome, team members not only need a shared understanding of the task itself, but also need a shared understanding about the process for approaching its achievement. In domains in which variations of the process are associated with high risks, standard operating procedures have usually been developed to ensure a uniform procedure of how to perform certain critical tasks (Grote et al. 2004; National Transportation Safety Board 1994). However, standard operating procedures are not suitable for non-routine tasks, which are typically ill defined in the beginning, and the requirements may also change during the problem-solving process. In such cases, the manner in which team members coordinate their processes cannot be predefined, but has to instead be decided based upon the characteristics of the task at hand (Edmondson and Nembhard 2009). Three aspects of process work can be distinguished (1) the planning of when to do what; (2) the procedure of how to solve a problem and which strategies or methods to use; and (3) reflection as meta-analysis of the process (Wetzstein and Hacker, 2004). Reflection (aspect 3) has been identified as a powerful mechanism of self-correction to adapt the process of responding to changing conditions or to unsuccessful results (Hackman and Wageman 2005; West 2002).

The *team model construct* of Fig. 10.1 refers to representations about the other members' individual abilities, knowledge, skills, and experience, as well as the roles and responsibilities each team member holds. As team members discuss the allocation of roles, they establish collective action regulation (Weber 1997), which is pivotal in helping a team to reach its goals effectively. Role allocation can be more or less centralised: In teams that have a formal or informal leader, it will be this person who verbalises the most coordination issues. If several members contribute to role allocation, responsibility and authority are likely to be more shared in the group.

The *climate model construct* of Fig. 10.1 describes the extent to which members feel that they belong to a particular group (Goodman et al. 1987). We define three communication processes that contribute to a cohesive climate: informal talk, appreciation, and mutual confirmation. Informal talk is non-task-related communication, which, according to Goodman et al. (1987), increases mutual knowledge about individual preferences and characteristics beyond the task. Appreciation refers to explicit positive statements concerning another team member or his or her contributions, and thus has an emotional component. Confirmation is another form of feedback that also indicates a positive 'evaluation' or a simple signal reinforcing the continuation of the conversational flow. These signals seem to be akin to the vocalisation in non-human primates to coordinate group movements (for details, see Chap. 13).

10.2.3 Development of Shared Mental Models

The concept of mental models implies that it is initially an individual representation: Each person develops his or her own mental models about the task, process, team, and climate. These mental models of individual team members can become shared mental models when communicating with other team members. In order to successfully work on a task as a team, the individual mental models of the members need to be shared to a certain extent – the general consensus among small group researchers being that the degree of sharedness and successful taskwork are generally positively correlated (e.g. Mathieu et al. 2008; Mesmer-Magnus and DeChurch 2009). Therefore, information exchange between team members is crucial, because when information is exchanged, the shared knowledge at the team level increases (see Fig. 10.1).

The main assumption of our model is that shared mental models develop from explicit, mainly verbal information exchange about the task, process, and team. This explicit verbalisation enables the development of shared team mental models, which in turn allows the team members to draw on similar representations. Teams with shared mental models are assumed to operate in a coordinated fashion without the continuous need for explicit verbal exchange: They coordinate their actions implicitly. We propose the following two stages in the development of shared mental models (see Fig. 10.1):

1. The first phase consists of explicit coordination; this is the moment of measurement t_1. By means of verbal communication, the team develops shared mental models. The verbal communication is the observable behaviour, which is assessed for further analysis.
2. The second phase starts after a certain degree of sharedness has been achieved, which is characterised by less explicit and more implicit coordination.

The following points in time (t_2, t_3, t_4) indicate that the exact moment of these two stages cannot be known in advance; therefore, more than two moments of measurement are necessary to analyse changes in the process. This conceptualisation draws on the idea of stage models of team development (Tuckman 1965), which purports that teams first need to form group norms before they can achieve their maximum effectiveness. Partly in accordance with this assumption is also Gersick's punctuated equilibrium model (Gersick 1988), which presupposes that groups develop through a sudden revision of a 'framework for performance' from phase 1 to phase 2 as outlined in Fig. 10.1. It is also in line with the idea that teams first establish coordination and then enact it (Arrow et al. 2000).

Our model of how shared mental models develop (Fig. 10.1) visualises the following six main assumptions:

1. Explicit exchange of information and knowledge enables the team to build shared mental models on the task, process, team, and climate.
2. After a period of explication, the team will achieve a degree of sharedness for each of the different types of mental models. The time required for explicit coordination depends on the characteristics of the task, the team members, the history of the team, etc.
3. For knowledge developed during the explication process, three different types can be distinguished: task-related knowledge, strategic knowledge, and transactive knowledge. Task-related knowledge comprises the factual knowledge about the task at hand. Strategic knowledge refers to knowledge about possible ways in which to approach a task. Compared to task-specific knowledge, strategic knowledge contributes to the task as well as the process and is augmented through exposure to different problems over time. Transactive knowledge comprises the knowledge about other team members: It contributes to transactive memory, which refers to the finding that team members memorise who knows what and whom to ask rather than remembering the knowledge content itself (Wegner 1986; Wegner et al. 1985).
4. Task-related knowledge is dependent on the specific contextual environment. Thus, any change in the problem or sub-problem necessitates explicit information exchange in order to arrive at a shared understanding. In contrast to interaction on the task, information exchange on how to collaborate on the given task can be valid for longer periods of work. Sharedness of the individual mental models on procedural aspects allows for implicit coordination; as long as there is no need for change, no further explications are needed.
5. Mental models about the team are assumed to serve two functions: a motivational function and a coordinative function. The motivational aspect refers to

maintaining a team climate that ensures sufficient cohesiveness so that the team members want to stay in the team together. The coordinative function encompasses the assignment of tasks, roles, and responsibilities according to the team members' preferences, capabilities, and experience (Stempfle et al. 2001). Explicit coordination is important for building shared mental models of the task, team, process, and climate; a shared mental model allows the behaviour of team members to be predicted. Thus, the need for further repetition of this knowledge becomes obsolete, and the frequency of explicit coordination after such a period of information exchange will decrease.

6. Individual mental models are not necessarily shared equally among all team members. Individuals might have similar background knowledge, share working experiences, or develop similar solution ideas. Those with the same disciplinary background often also share the same jargon, which in turn makes it even more difficult for team members with a diverse background to reach a shared understanding. Earlier research has pointed out that dyads in a team often develop a shared mental model, and through this shared mental model teams achieve a better performance (Bierhals et al. 2007). The frequency of interactions in the team will influence which team members share their mental models more than others.

10.3 Observational Approach to Measuring the Development of Shared Mental Models

The following section explains our methodological approach, which will be illustrated in an analysis of a case study of two team meetings. The definition of shared mental models as being the degree of convergence among team members with regard to the content of known elements, as well as the structure between elements (Mohammed et al. 2000), is purely descriptive. It does not provide any information about how to measure these elements nor the relationships between the elements. For assessing the components of mental models of a person working on a given task, questionnaires can be used to directly request knowledge of the participants, or a thorough team task analysis can be conducted (see Chap. 9). Common methods such as Pathfinder (Schvaneveldt 1990) or concept mapping (Tergan and Keller 2005) attempt to reveal a snapshot of the relationships between key elements in an individual's mind, which these methodologies often depict graphically. For an overview of measurement techniques, see Langan-Fox et al. (2000) and Mohammed et al. (2000), as well as Sect. 9.3.2.1.

For complex tasks such as design problems, no predefined routines exist to solve such a problem. Thus, key elements with regard to the task are dependent on the problem definition and solution ideas of the designer, and therefore cannot be identified easily beforehand; the solution space for most problems in design is by far too big. Continuous observation over time provides a possible solution to

the challenge of measuring the development and adaptation of shared mental models during such problem solution processes. In the absence of predefined criteria, observations rely on overt behaviour such as team communication as a valuable way to obtain access to the development of team mental models. The underlying argument is that team members themselves also cannot read each others' minds and therefore have to rely on what is being said to develop shared understanding.

Our methodological approach therefore analyses explicit verbal communication as a natural observational angle into team mental models. All verbal utterances are coded according to the categories of the proposed model, from which we, in turn, infer the development of team mental models.

10.3.1 Coding Scheme

We developed a categorisation system of verbal communication using the above-mentioned four types of team mental models: task, process, team, and climate (see Table 10.1). If more than one topic was addressed within one utterance, the statement was split so that each part could be assigned a single category per categorisation system. Verbal activities were coded by three members of the research team, and Fleiss' kappa (Fleiss 1971) was found to be 0.72 on the level of the subcategories.

10.3.2 Measuring Dissociate Versus Comprehensive Sharedness

The second measure addresses whether sharedness is established in a *dissociate manner* based on dyadic interactions, or in a *comprehensive manner* that encompasses all members of the team. In order to calculate this aspect of sharedness, a contingency analysis is conducted to determine how often each person follows up on another person's utterance: Every time person B follows an utterance of person A, this is counted as an instance of B replying to A. As this relation is unidirectional, the instance of A replying to B is added as additional information regarding the explicit communication between A and B in the network. The results are mapped as a network of all individual contributions. If sharedness is dissociate, only a subgroup of the team actively shares its mental models. The other team members may interpret the behaviour of the active team members as being more knowledgeable or more powerful. It remains unclear from the verbal interaction if those who are only listening are also incorporating what has been said into their mental models. A more comprehensive form of sharedness is likely to arise in teams with equal status and an even spread of knowledge, or it could be the result of standard operating procedures that require read-back behaviour for mission-critical situations.

Table 10.1 Categorisation system for verbal activities (explicit coordination) in teams

Task	
Problem definition and elaboration	Defining the problem, elaborating and analysing the constraints, the requirements, and the goal of the task: e.g. "The main focus is that style pen where you'll create a set of patterns by moving on plain white paper."
New solution idea or new solution aspect	Stating a new product-idea or a new solution for an earlier defined problem or sub-problem or new aspects building on an earlier mentioned solution idea: e.g. ". . .maybe like a flat base with a sort of universal joint like a windsurf mast."
Solution analysis	Analysis of properties and the feasibility of a solution idea; analysis of the usage of a product idea and its potential applications, e.g. by referring to similar products; and evaluation of a solution idea by appraising its feasibility or analysing failure and safety aspects: e.g. "With this feature you get both thick and thin lines."
Explanation	Clarification of questions and explanations about specific (technical) issues, e.g. by referring to specialised knowledge: e.g. "How's that achieved? Is that achieved by a plastic that's bendable?"
Solution decision	Making a solution definitive by accepting it in the whole team: e.g. "So we stick to the second option, the barcode thing."
Process	
Statements on organisation re when to do what (planning), how to approach the task, e.g. how to apply a method (procedure), and utterances about what and how the team is doing (reflection)	
Planning	Statements on the organisation when to do what: e.g. "We're going to try to deal with that a fair bit on Monday."
Procedure	Statements about how to approach the task, e.g. how to apply a method: e.g. "I think we should concentrate on what the mechanism might look like."
Reflection	Statements about what and how the team is doing: e.g. "I didn't realise what this was. This is a prototype."
Team	Role allocation to team members and references to personal abilities, knowledge, skills, or experience: e.g. "Chris, could you work this out in detail [. . .], you know best how to do it."
Climate	All aspects that indicate signals about group coherence are included in this category: appreciations about a solution idea or a problem definition, confirmation, and informal communication (e.g. joking).
Appreciation	Statements about a solution idea or a problem definition. All aspects that indicate signals about group coherence: e.g. "It's an interesting idea."
Confirmation	Positive statement which confirms the other member(s) of the team: e.g. "Yeah."
Informal communication	Statements which do not refer the actual task: e.g. "Your housemates are not going to be pleased."
Other	All utterances that are not defined in another category

10.4 Illustration of the Methodological Approach in a Case Study

In order to illustrate the application of our methodological approach, we report a case study that was conducted as part of the Design Thinking and Research Symposium held in London in July 2007 (see McDonnell and Lloyd 2009). The organisers had recorded meetings of design teams in companies and provided participants with video recordings as well as verbal transcripts of the meetings. Each research team analysed the data set (or parts thereof) according to their research interests and methodology. The data set consisted of two meetings, during which a team of engineers and other professionals generated ideas for a new product. All verbal data were categorised following these steps: The transcribed group videotapes were segmented into utterances, and then coded according to two distinct categorisation systems. The analysis focused on how the verbal communication in the defined categories developed over time in terms of task, process, team, and climate.

For coding, the software programme Mangold InterAct (version 7.0, http://www.mangold.de) was used. This programme enables the coding of many types of behavioural data per time unit, and the coded results can be easily transferred into statistical programmes.

10.4.1 Sample

Seven members from a technology development company attended both meetings. Not unusual for projects in industry, there was some fluctuation of attendees between Meetings 1 and 2, and there were no clear boundaries for what constituted membership of this design team. The first meeting included a business consultant acting as the moderator, an electronics engineer, a business developer, three mechanical engineers, an expert for ergonomics and usability issues, and an industrial design student who was doing an internship with the company. The intern also functioned as project leader. In the second meeting, two electronics/software experts and one electrical engineer participated instead of the business consultant and the two mechanical engineers. No further information about team tenure or experience was collected by McDonnell & Lloyd.

10.4.2 Procedure

The task was to develop a print head mounting for a thermal printing pen. The team was instructed to brainstorm in both meetings. Prior to the first meeting, the meeting participants had been asked to consider analogies or possible solutions for the

assignment and were informed about the major topics to be discussed during each session.

The frequency of verbal activities (and thus the development of mental models) over time was analysed by comparing the two meetings, as well as the first and second halves of each meeting. For purposes of structuring our coding, a timeline of the frequency of codes was established for segments of the meeting. In order to compare frequencies, the segments were based on duration rather than content, as they had to be of equal length and not too short for statistical analysis of frequencies. Consequently, each meeting was divided into five segments.

10.4.3 Hypotheses

The following section explains our hypotheses regarding the development from unshared to shared mental models derived from the framework described above.

H1 Task. At the beginning of the meeting, verbal utterances should be related to problem definition, explanation, solution generation, and evaluation. Assuming that the group works together for the first time, shared understanding would be low, and thus a high number of explanations is expected. As taskwork progresses, knowledge about the task and possible solutions is expected to increase, and thus fewer problem definition utterances and explanations should occur. The team is expected to continue generating new ideas and analyse solutions, so these task-related utterances should increase over time.

H2 Process. A shared mental model related to the process will be developed by an increase in planning and procedural aspects in the first phase. In the second phase, only rescheduling and minor adaptations should be necessary, while reflection is likely to be useful throughout the whole process. Once explicit coordination has led to a shared mental model about how and when to do what, implicit coordination can occur. The frequency of process utterances should therefore decrease over time.

H3 Team. Transactive knowledge exchanges, such as role allocation utterances and references to each other's knowledge and skills, are expected to be more frequent in the first phase and should decrease after shared understanding on these issues has been achieved.

H4 Climate. Team climate utterances are expected to be initially high when team members strive to gain mutual acceptance, and to then decline once a certain level of team cohesion has been established. If the climate is negatively affected by conflicts or inappropriate group member behaviour, an increase in climate-related utterances will be needed once again to regain a positive climate in the team.

H5 Dissociate versus comprehensive sharedness. A more equal distribution of interactions between members will be related to a more comprehensive sharedness within the whole team. If dissociated patterns emerge in terms of increased levels of interaction in dyads or subgroups, this will be associated with the team's mental models being shaped and shared by only those members.

10.4.4 Findings on the Development of Sharedness in the Case Study

In the following sections, the results from the case study are discussed in terms of our proposed hypotheses.

10.4.4.1 Task: Extent of Sharedness Indicated by Degree of Lower Number of Problem Definition and Solution Analysis and Explanation

Figure 10.2 shows the frequencies of utterances in the team along five moments (M) in time in both meetings (M1.1–M1.5 and M2.1–M2.5).

There are two results of further interest: those for *problem definition* and those for *explanations and solution analysis*. According to our hypotheses, sharedness in the team should be indicated by a decreased frequency in problem definition utterances. The results show that within each meeting, the amount of problem definition significantly decreased from the first to the second half of the first meeting ($\chi^2 = 10.14$; $p < 0.01$). While this result confirms our hypothesis, the comparison between the two meetings tells a different story. The frequencies of problem definition utterances increased significantly from the first to the second meeting ($\chi^2 = 24.26$; $p < 0.01$), and even in the second half of Meeting 2, the frequency of problem definition utterances was significantly higher.

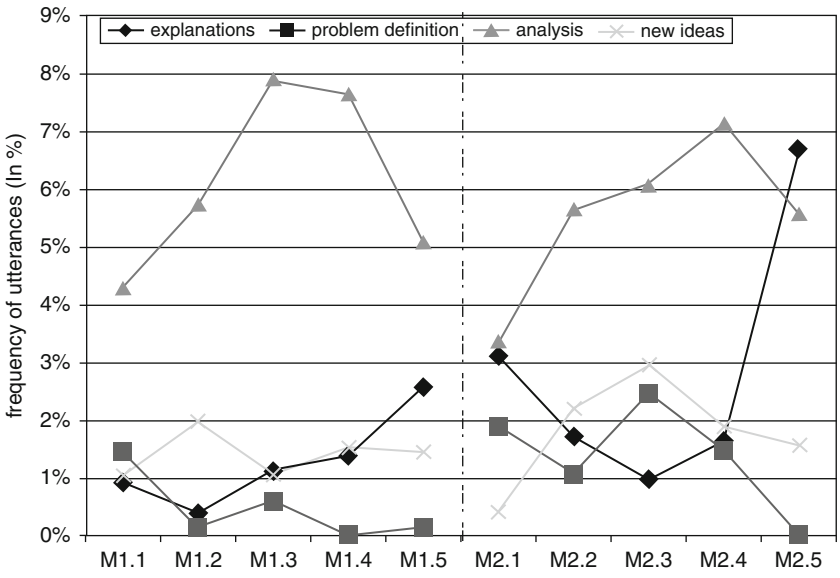

Fig. 10.2 Task communication: percentage of problem definition, solution analysis and explanations for both meetings, each divided into five equal parts

Explanations and solution analysis were expected to increase during the first meeting, but decrease in the second meeting when a shared mental model had been established. This was not found for the data presented here (see Fig. 10.2). The frequencies of explanations increased significantly from the first to the second meeting ($\chi^2 = 23.8$; $p < 0.01$); furthermore, the frequency also increased suddenly towards the end of each meeting.

The frequencies of solution analysis decreased, albeit not significantly. However, it can clearly be seen that analysis utterances increased during each meeting as more detailed, unshared aspects that had not been mentioned before were discussed. Also, explanations became more frequent towards the end. Utterances categorised as new ideas did not significantly decrease between the meetings. However, analysis utterances became more frequent after new ideas had increased in frequency, thereby showing that once a new, unshared topic was introduced, explicit communication about this topic was required.

These findings suggest that the team still felt the need to discuss the problem definition and to clarify the problem in the second meeting, which would suggest that sharedness had not been developed to a sufficient degree until then. However, a qualitative analysis of the latter half of Meeting 2 showed that a more likely explanation is that the group began to tackle more intricate problems and discussed issues at a deeper level. The problem definition was not actually redefined – the content issues were the same, referring to the powering, charging, cost, and heat of the product. Some members reiterated these issues to reinforce the importance of the issues, and new solution ideas were judged against the already agreed-upon requirements.

10.4.4.2 Process: Sharedness Indicated by a Decrease in Planning Utterances

According to our model, we expected that after a phase of explicit coordination in terms of planning and procedure, the team would develop a shared understanding on these issues. This increase in sharedness should lead to more implicit coordination. Thus, the number of explicit process utterances should decrease towards the end of a team meeting. Reflections on *what* the team is doing and *how* they are proceeding should not decrease dramatically, because teams should maintain awareness about their process (a 'meta-view') throughout the meeting.

This expected negative correlation between implicit and explicit communication once sharedness has taken root is exactly what happened. There was a significant decrease in the summarised process utterances from Meeting 1 to Meeting 2. Process utterances decreased most dramatically between the first and second parts of Meeting 1, whereas the frequency of process utterances stayed the same during the second meeting. In analysing the three process categories of planning, procedure, and reflection in detail (Fig. 10.3), the distribution of these categories shows that there were different developments for 'planning' and 'procedure' on the one hand, and 'reflection' on the other. Reflection should lead to a better meta-view regarding one's own procedures and planning and can overcome content and causal

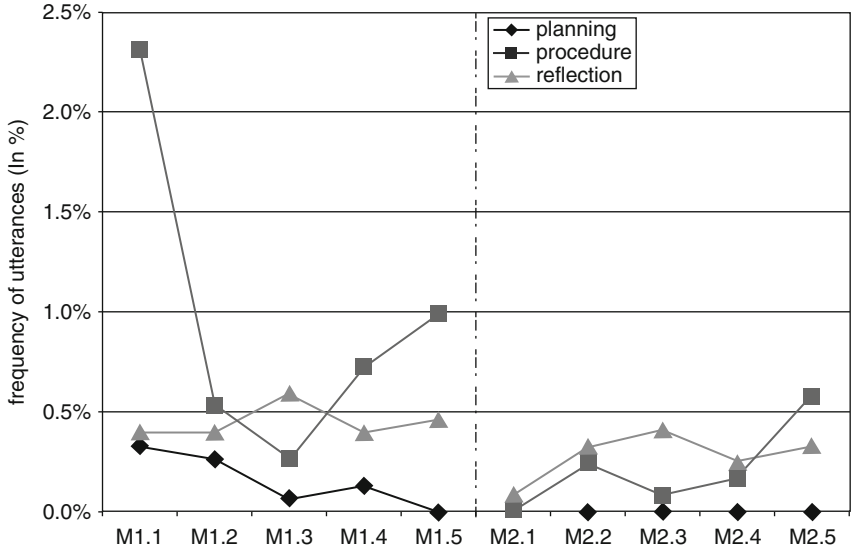

Fig. 10.3 Process communication: frequencies of planning, procedure and reflection utterances for both meetings, each divided into five equal sections

gaps in mutual understanding when sharedness is missing or lost. Reflection was therefore not expected to decrease during the meeting, which is what was found.

10.4.4.3 Team: Allocation of Tasks, Roles, and Responsibilities

Explicit team coordination was expected to be relatively high, especially in the first phase, and expected to then decrease in the second phase if the team had achieved a shared understanding on coordination. Our data of the design team were very clear: There was hardly any explicit team coordination, with only 17 utterances made in both meetings (Fig. 10.4). This surprising result can be attributed to the nature of the meetings, which were set up as brainstorming sessions. Thus, both meetings focused on gathering and developing new ideas; task allocation beyond the meeting was not discussed.

10.4.4.4 Climate: Sharedness Indicated by Continuous Backing Up

Although mainly observed as signals of attentive listening (e.g. 'Yeah'), the cohesion utterances made this category the highest frequency in both meetings. Following Owen (1985), who found that members of cohesive groups are more likely to engage in active communication, climate utterances are very likely to be a prerequisite for the development of team mental models. Based on our two-stage

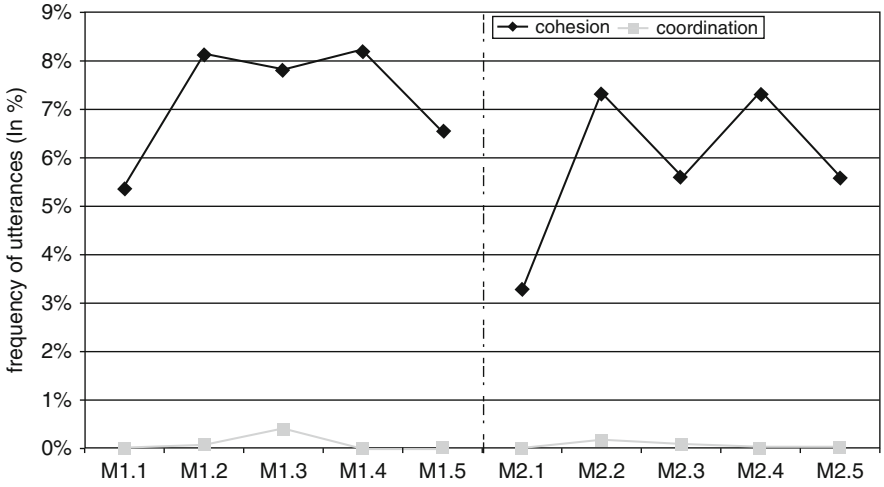

Fig. 10.4 Team and climate communication: percentage of utterances of team coordination and climate for both meetings, each divided into five equal parts

model, a decline of climate utterances over time was expected (see Fig. 10.4). There was no significant difference between the two meetings, but within each meeting climate utterances initially increased and then decreased.

10.5 Analysis of Dissociate Versus Comprehensive Sharedness

The extent to which sharedness was established in a dissociate vs. comprehensive manner was measured by analysing which group member most actively communicated and with whom. Individual contributions of the team members and their interactions were explored using a communication network analysis. A contingency analysis for all speakers was applied to determine who talked to whom and how often, thereby identifying dyads within the team. Figure 10.5 shows a network based on the contingency analysis of the individual contributions (the names are fictitious as used in McDonnell and Lloyd 2009). The thickness of the lines indicates the amount of individual talking in a given dyad, thus indicating how the information was transferred within the team. Individuals with many thick lines connected to them were more central in the team; those with thin lines were not highly involved. The most obvious dyad was Tommy and Todd, who talked to each other more than to any other team member. Both of them were experts in the field that was most relevant to the task, and therefore presumably had the greatest need, as well as capacity, to create a shared mental model about the topic. It is also noticeable that Alan, the facilitator, spoke considerably more to Tommy, Todd, and Jack than to the other members. They, in turn, communicated more with Alan. Again, the most likely reason is that these people had the most relevant knowledge

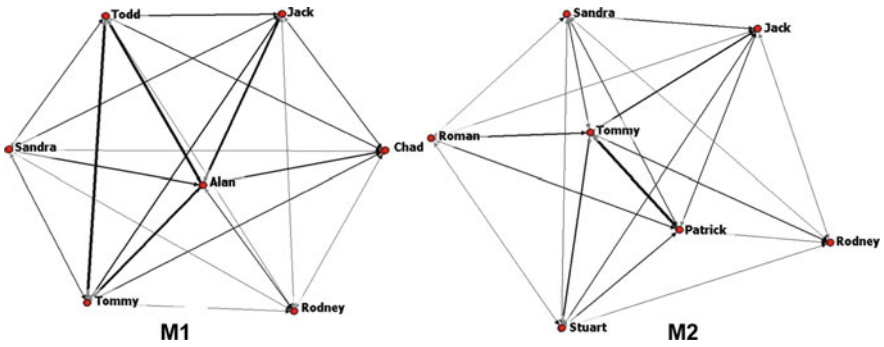

Fig. 10.5 Network based on the contingency analysis of the individual contributions, providing information about the inclusiveness of sharedness in the team

for that task, thereby making sure they shared an understanding about these issues. This is in line with the idea that in some teams it is sufficient for dyads of experts to share their knowledge.

The second meeting revealed a clear dyad between Tommy and Patrick, with Tommy replying to Patrick with 34.5% of his utterances and Patrick replying to Tommy with 55.8% of his. Again, these two team members were the experts for the task at hand. All other members spoke mainly to Tommy, who could be seen as an informal group leader. Additionally, Patrick could be seen as a second facilitator in the team, as he led the discussion about another topic with Roman and Sandra.

Interestingly, this analysis of the inclusiveness of sharedness can also help to reveal why some individuals are less involved in a meeting. For example, Rodney had very weak links to all members except to Tommy. Rodney was a trained industrial designer who could not contribute much to the actual meeting apart from aiding Tommy, who was the facilitator. A network analysis can thus help to investigate dyads in a team and, in turn, to understand the development of sharedness within these dyads.

10.6 Discussion

This chapter focused on the question of how far sharedness can be measured on the basis of observed data, how it develops over time, and to what extent sharedness encompasses the entire group vs. concentrates in dyads. According to our theoretical concept of the role of shared mental models in the transition from explicit to implicit coordination, hypotheses were derived and tested. Our approach presents a methodology for studying the development of shared mental models based on the analysis of overt, explicit behaviour. As such, the approach could also be applied in other domains beyond designing by – if necessary – adapting the category system to the task context, although the task categories of this categorisation system should be

sufficiently generic for most areas of complex problem solving. For studying non-human primates, the methodology would obviously need to be adapted, but the transition from explicit to implicit coordination may also be found in non-human primates, for instance in the initiation of offspring into the habits of the group, or in newly formed conspecific or mixed-species groups.

Our specific emphasis in this chapter was the development of shared mental models over time. Based on the proposed model (Fig. 10.1), the frequency of certain verbal utterances in our study sample was expected to initially increase in order to achieve sharedness and then decline over the course of a meeting as a result of increased sharedness. This prediction refers to the two phases of sharedness for coordination of task, process, team, and climate aspects.

In accordance with our assumptions, the process of coordination showed the transition from explicit to implicit coordination for the planning activity, considered to be the most important part of process coordination. However, in this sample, no explicit team coordination could be observed in either of the meetings. In our previous field research, we also found only a limited amount of coordination (Stempfle and Badke-Schaub 2002), but typically in these previous studies there were at least some utterances regarding task allocation and additional post-process project planning beyond the meeting. However, the team in this study did none of these, which presumably is related to the specific situation: The team already shared a common history, as there had been previous team meetings. The two observed meetings in this sample were designated as brainstorming sessions where decisions are typically deferred; additionally, only some members had direct responsibilities for execution of work beyond the meeting.

The results of the meetings further showed that the utterances regarding problem definition increased significantly from the first to the second meeting, which would indicate that there was no sufficient sharedness related to problem definition – which makes sense given the change in membership composition from one meeting to the next. The same was found for the number of explanations, which also increased significantly from Meeting 1 to Meeting 2. According to the hypotheses, both results would indicate a low sharedness in the team related to task-specific knowledge. However, the qualitative analysis revealed that these two findings were related to a more in-depth discussion of a new sub-problem. The findings, therefore, do not violate the assumptions of the model but rather indicate that the process of creating sharedness started again in Meeting 2 at a more detailed level – as is perfectly normal for the progression of design work. This could be integrated in the model by adding a further dimension referring to the resolution level of the observed behaviour.

Overall, this two-phase model of the development of team mental models provides a framework for measuring the development of shared mental models in teams by addressing the temporal, dynamic dimension of the development of shared mental models. Its predictions and the results from the case study are also in line with models of group development such as Tuckman (1965) and results of empirical investigations such as the observations of Gersick (1988), who found that project groups worked with a muddling-through strategy until halftime of the task

completion, or until critical events occurred that necessitated a (re-)structuring process in the group. We propose that the group needs the first part of its time to explicate the individual representations (transactive, task, and strategic knowledge) and through this process eventually develops shared mental models.

A limitation of the approach is that the content of mental models is only inferred from the verbal communication. Unless the content of mental models is simultaneously measured using another approach (such as Pathfinder), it is impossible to distinguish between low-coordination utterances as a sign of high sharedness and implicit coordination, or as a sign of a lack of coordination because team members inappropriately assume that they share the same mental model. The rules with regard to what is explicated may also vary between domains and teams. In the case study presented here, we had no control over how the data were collected and could therefore not measure the content of mental models at the start and end of the two meetings. However, we would still advise scholars to use this model and methodological approach in combination with other approaches of measurement of shared mental models, as the constructs of the development of shared mental models were confirmed.

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