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Creating Shared Understanding in Heterogeneous Work Groups: Why It Matters and How to Achieve It

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Abstract: Shared understanding has been claimed to be crucial for effective collaboration of researchers and practitioners. Heterogeneity in work groups further strengthens the challenge of integrating understanding among diverse group members. Nevertheless, shared understanding and especially its formation are largely unexplored. After conceptualizing shared understanding, we apply collaboration engineering to derive a validated collaboration process module (compound thinkLet "MindMerger") to systematically support heterogeneous work groups in building shared understanding. We conduct a large-scale action research study at a German car manufacturing company. The evaluation indicates that with the use of MindMerger, team learning behaviors occur, and shared understanding of the tasks in complex work processes increases among experienced diverse tool and dye makers. Thus, the validated compound thinkLet MindMerger provides designers of collaborative work practices with a reusable module of activities to solve clarification issues in group work early on. Furthermore, findings from the field study contribute to the conceptualization of the largely unexplored phenomenon of shared understanding and its formation.

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BECAUSE OF THEIR COMPLEXITY, MANY TASKS IN ORGANIZATIONS exceed the cognitive capabilities of any individual and thus rely on the collaboration of heterogeneous, cross-disciplinary groups [21, 34]. Previous research shows that, under certain conditions, diverse groups can perform better on complex tasks than do homogeneous groups [8, 52]. While group members usually do not need to have expertise in all fields tackled by a complex project, "they have to be able to integrate their knowledge bases in a sensible manner" [28, p. 21]. We refer to this phenomenon as *shared understanding.* Building a shared understanding (SU) "is important because people frequently use the same label for different concepts, and use different labels for the same concepts. People on a team also frequently use labels and concepts that are unfamiliar to others on the team" [49, p. 127]. Differences in meaning assigned to key concepts, in mental models or in information, can interfere with productivity of collaborative work if they are not clarified early on [28, 29, 40]. In their recent study, Piirainen et al. [44] identify building a shared understanding as one of five critical challenges of collaborative design from the design science literature and practice, especially in the early problem definition and artifact construction phases. This challenge can be complicated due to, for example, a lack of overlap in experience; shared context and language of the actors; the wicked, ambiguous nature of design problems; or the disruption of routines, which influences how a group forms and performs [22].

There is ample evidence of the positive effects of shared understanding discussed in prior work, such as on performance (quality and quantity of results) [34, 37], group member satisfaction [34], coordination of activities among group members [26], reduction of iterative loops and re-work [28], innovation [29], or team morale [17]. If techniques and processes can be designed that predictably support the creation of shared understanding in heterogeneous groups, these groups are expected to gain efficiency in their work and produce better results [40].

As little is known on what leads to shared understanding, practitioners need guidance on how to evoke processes for shared understanding deliberately and repeatedly. Collaboration engineering, as an approach to designing and deploying reusable work practices for high-value recurring tasks without the ongoing intervention of a professional facilitator [49], has identified "clarify"—the process of moving from less to more shared understanding—as one of six recurring patterns of collaboration [14]. There has been a lot of fruitful research on other patterns, such as generate [45, 46] and build consensus [32], that has led to theories [9, 12, 13] and to validated standardized facilitation techniques (thinkLets [11]) that "can be used as conceptual building blocks in the design of collaboration processes" [33, p. 613].

Little attention, however, has been paid to the "clarify" pattern, and shared understanding as a core construct within the clarify pattern still is a fuzzy phenomenon subject to conceptual confusion [1, 35]. It would thus be valuable to gain deeper understanding of the clarify pattern of collaboration in order to (1) provide collaboration engineers with documented work practices to be reused in their own designs, (2) enrich exploratory research on shared understanding from related disciplines with a collaboration engineering perspective, and (3) contribute to clarification of the fuzzy construct of shared understanding.

We therefore (1) conceptualize shared understanding and theorize on an initial frame of potential determinants and effects of shared understanding, (2) use these theoretical approaches to inform the development of a repeatable collaboration process module that leads to better shared understanding in group work and thus to better group results, and (3) validate empirically the designed collaboration process module for shared understanding while exploring the research frame. We propose a collaboration process module for shared understanding that can be used by designers of collaboration processes to repeatably evoke the clarify pattern. We use the thinkLet [11] notation and logic, documenting the collaboration process module in the form of a compound thinkLet: a larger, predefined sequence composed of several packaged thinkLets.

While a basic version of the process logic itself has been proposed [5], the current paper expounds on using and advancing the compound thinkLet MindMerger in the challenge of shared understanding and knowledge integration in heterogeneous work groups in a real-world setting at a German automobile manufacturing company [6]. We chose an action research approach to develop a solution for the specific practical problem situation, while simultaneously investigating the phenomenon of shared understanding and knowledge integration in heterogeneous teams. By advancing and validating the compound thinkLet in a real-world setting, we cautiously generate new insights on the mechanisms that lead to shared understanding in heterogeneous group works.

The rest of the paper is organized as follows. First, we point out our underlying conceptualization of the fundamentals of shared understanding, including a new definition of the phenomenon. The next section describes the action research approach we use within the design research process and the collaboration engineering methods applied. We then outline the action research phases with the thinkLet development and validation in the real-world setting. The findings are discussed with respect to the design and lessons leaned for shared understanding theory development. The paper closes with a consideration of implications, limitations, and outlook on future research.

Related Work—Fundamentals of Shared Understanding

Confusion exists in the literature on the definition of shared understanding, its antecedents and effects, as well as how shared understanding can be operationalized and measured. Due to the broad consideration from different research perspectives, no single widely accepted definition has been established [5, 40]. Due to a lack of validated explanatory models for shared understanding, we review potential constructs and mechanisms related to shared understanding in order to derive initial clues for design.

Shared Understanding

Shared understanding and related terms (e.g., shared mental models, team mental models, group cognition, sense making) are used and defined in different ways in different research streams. Previous definitions include “the ability of multiple agents to coordinate their behaviors with respect to each other in order to support the realization of common goals or objectives” [47, p. 3] and “mutual knowledge, mutual beliefs, and mutual assumptions” [41, p. 36].

Sharedness encompasses various aspects, such as “similarity, agreement, convergence, compatibility, commonality, consensus, consistency, and overlap” [40, p. 880]. Two differing interpretations of “shared” can be found, namely, shared as the joint possession of some resources versus the division of a resource between multiple recipients [47]. While the latter refers, for example, to the distribution of tasks or knowledge among different people, the former covers the phenomenon we see in shared understanding. Groups who are engaged in collaborative work need to have some knowledge and understanding in common, which functions as a joint reference base in order to work productively. Thus, we focus the definition of “shared” for our purpose as a resource being possessed jointly by several people. A definition of shared understanding should reflect this view.

“Understanding is an ability to exploit bodies of causal knowledge (i.e., knowledge about the antecedents and consequents of particular phenomena) for the purpose of accomplishing cognitive and behavioural goals” [47, p. 2]. This definition of understanding highlights the importance of both knowledge as facts and the structure of this knowledge. Causal knowledge is necessary for directed action toward a goal. Seeing understanding as an ability to exploit knowledge strengthens the viewpoint that understanding is more than knowledge, but a cognitive state of the knower. As an ability, understanding is not static, but rather a dynamic state that can change over time due to, for example, learning.

As individual understanding is a dynamic state and sharedness is grounded in the concept of joint possession of resources, shared understanding is based on “the overlap of understanding and concepts among group members” [41, p. 36]. It is thus a dynamic state of the group related to some object of knowledge that can take continuous levels. The object of knowledge can be of various structures and contents, such as the group task, process, or technology used. Research on the “build commitment” pattern of collaboration has identified five categories of sources of a lack in consensus closely related to domains for shared understanding: differences in the meaning assigned to words, different mental models, information differences, differences in individual goals, and differences in taste [25, 32]. The first three categories are also common domains of shared understanding. Shared meaning is the degree to which group members interpret a concept in the same, of a number of possible ways. Shared mental models refer to the degree to which mental models of cause and effect are similar among group members. Shared information means the degree to which people in a group concur on the value of the properties of things in which they are interested.

We exclude the other two categories from our scope of shared understanding, as our focus is on collaboration toward a group goal. A group might be working effectively toward a group goal, although individual goals are different. Mutual understanding of private goals as the degree to which group members comprehend the private goals that motivate teammates to work toward the group goal might increase shared understanding, but shared goals are not a prerequisite. Differences in taste are closely related to individual goals. Knowing about the goals and tastes of other group members can be beneficial for negotiating consensus, but if the individual goals all harmonize with the group goal, no shared individual goals are required for shared understanding.

Taking the above into consideration, we define shared understanding as *the degree to which people concur on the value of properties, the interpretation of concepts, and the mental models of cause and effect with respect to an object of understanding.* For example, members of a product development team may have different assumptions on the physical values of properties of the material they are supposed to use for a new prototype, such as density or heat resistance. They might interpret the same concepts differently, such as flexibility as bendability or as adaptability to different uses. Finally, they might diverge on their understanding of what a change in some property induced by a design choice may imply for the functioning of the whole prototype, as they assume different mechanisms and have different mental models of the whole product. All three categories of shared understanding may evolve gradually during collaborative work.

Antecedents of Shared Understanding

This section provides an overview of the current state of the literature and develops a research frame on the antecedents of shared understanding to inform the design of a compound thinkLet for shared understanding. As shared understanding is a dynamic state, factors that are positively related to an increase in shared understanding need to be identified. If those factors can deliberately be influenced by, for example, staffing of the team or by evoking certain collaborative mechanisms, we will be able to design collaborative practices for shared understanding.

Kleinsmann and Valkenberg [29] identify antecedents on an actor, project, and company level expected to influence the construction of shared understanding in groups. Langan-Fox et al. [34] distinguish between individual differences and environmental factors as determinants of shared understanding. Among the factors related to the individual and the group are, for example, individual personality and skills, team familiarity, authority, and diversity [29, 42]. Environmental factors, such as physical proximity, incentives, communication support, and organizational culture, have also been discussed [18, 26, 29, 34]. Although the aforementioned factors should be taken into consideration by collaboration engineers, team staffing or environmental conditions are often determined by the scope of a collaboration setting, and can only be influenced to a limited extent by design. Therefore, determinants concerning the collaboration process have also been analyzed [29], such as reasoning and communication, visualized beliefs and evidences, separation of individual and shared activity spaces, and training [17, 18, 19, 39]. Despite the broad coverage of shared understanding, we did not find any validated theoretical model with well-defined constructs to explain a set of antecedents to shared understanding. Some research has started to examine the relationship between interaction and group learning/shared understanding (see, e.g., [20, 27]). However, a lack of knowledge can be identified concerning the specific behavioral patterns that lead to the construction of shared understanding and the underlying constructs [48].

For the purpose of this paper, we focus on exploring team learning process variables, as they provide reference points for design choices. Mohammed and Dumville note that "in order for a team to achieve a shared, organized understanding of knowledge about key elements in the relevant environment, changes in the knowledge or behavior of team members will most likely occur. Therefore, group learning plays a significant role in the development, modification, and reinforcement of mental models" [39, pp. 97–98]. This view is coherent with a constructivism perspective on knowledge and shared understanding. In line with Piaget [43] and Vygotsky [50], knowledge is constructed in the mind of the learner resulting from a learning process, where new experiences are organized and assimilated to existing cognitive structures of previous knowledge. Knowledge structures are constantly tested to fit reality.

Constructive learning theory, on the one hand, explains why different people have diverse understanding of the same reality, as knowledge is constructed within each individual. In this view, there is no objectively, right knowledge on a certain object of interest that matches reality, but rather different conceptualizations that may "fit" reality better or worse. Therefore, we work with the assumption that shared understanding is not per se present in a group of people receiving the same information on a certain object of understanding (e.g., group task) and it cannot be taught as universal facts. Furthermore, understanding should not be assessed as right or wrong, but in relation to the other group members' conceptualization. On the other hand, constructivism provides an explanation of why shared understanding can evolve in a group of people who are acting in the same environment and are probably interacting. As we constantly test our understanding of a certain object against reality, our understanding will most likely assimilate if we face the same reality. Communication and interaction with other group members will have similar effects, as we might adapt knowledge structures when we face information that cannot be assimilated to our current ones. Interaction with one another and the environment will thus give impulses for changes in our understanding, and most likely produce a convergence of the group's understanding [7]. We try to make use of these interaction mechanisms by deliberately designing processes to support the construction of shared understanding.

Grounded on group cognition research from learning sciences and organizational sciences, Van den Bossche et al. [48] analyzed the construction of shared understanding by developing and testing a model of the team learning behaviors leading to shared understanding (see Figure 1). The authors examined three kinds of team learning behaviors: the effect of construction, co-construction, and constructive conflict on the development of shared mental models. Furthermore, they measured how shared mental models mediate the effect of team learning behaviors on team performance.

Construction of meaning is referred to as "when one of the team members inserts meaning by describing the problem situation and how to deal with it, hereby tuning in

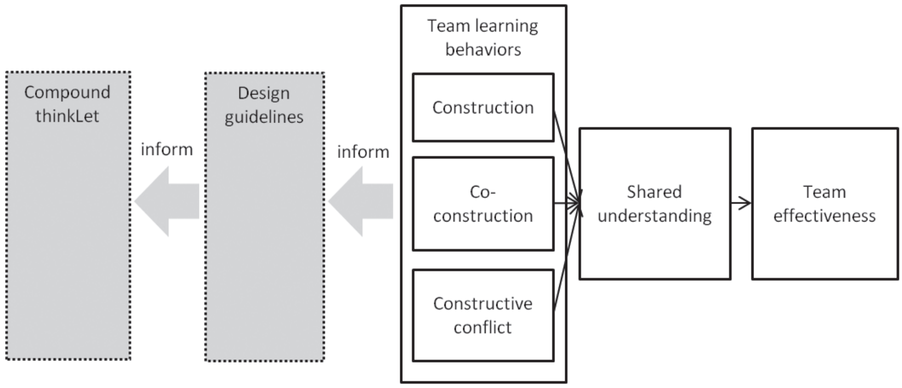

Figure 1. Theory-Guided Compound thinkLet Development

Source: Adapted from Van den Bossche et al. [48].

to fellow team-members. These fellow team-members are actively listening and trying to grasp the given explanation by using this understanding to give meaning to the situation at hand" [48, p. 287; based on 51]. Collaborative construction (co-construction) is "a mutual process of building meaning by refining, building on, or modifying the original offer in some way" [48, p. 287; based on 3]. Construction and co-construction lead to mutual understanding. However, mutual understanding does not mean that group members share the same perspective or are able to act in a coordinated manner. As shared understanding in collaborative work is a means to acting in a coordinated manner, mutual agreement on one perspective is thus necessary. Mutual agreement is achieved through constructive conflict, which means "dealing with differences in interpretation between team members by arguments and clarifications" [48, p. 288].

Following Van den Bossche et al.'s [48] model, collaborative groups should express, share, and listen to their individual understanding (construction), discuss and clarify them to reach mutual understanding (co-construction), as well as controversially negotiate an agreement on a mutually shared perspective (constructive conflict). Van den Bossche et al. [48] found that these team learning behaviors positively influence the construction of shared mental models among students working on a business simulation game.

Research Approach

Our study is characterized by the framework of design science research [24]. We followed the design science research process and completed all cycles of design science research [23]. We studied a design process (development of the compound thinkLet), and a designed object (the compound thinkLet MindMerger). We completed the relevance cycle by identifying the construction of shared understanding as an important class of unsolved problems in the field. We designed and tested six iterations of MindMerger as a generalizable solution (design cycle) and took the solution back into the field to test with real problem stakeholders, completing a relevance cycle. We completed a rigor cycle by drawing on scholarly literature from group cognition and collaboration engineering to inform our design choices and report our results back to the research community. Within the design science process, we followed the standards of rigor for exploratory research and conducted an exploratory action research study with age- and experience-diverse groups of tool and dye makers at a large German car manufacturing company in order to generate new insights on the mechanisms leading to shared understanding and to develop and validate a compound thinkLet design. As shared understanding is a complex phenomenon in real-world settings and no conclusive body of theory is available to explain the mechanisms leading to shared understanding and the underlying constructs, we chose an exploratory research design to allow for unexpected findings and flexible design adaption. Exploratory research allows the researcher to gather broad observations, examine the phenomenon in a holistic way, and react flexibly to new insights. To allow for a holistic view and compensate for the weaknesses of individual data collection methods, a combination of several data collection methods was selected.

Action Research Approach

Action research was chosen as research framework for our study. Action research is a research approach from the social sciences, where the researcher gets actively involved in the intervention and interacts with the members of the focal organization. On the one hand, it aims at changing the social system and solving a concrete real-world problem. On the other hand, new insights into the system and the phenomenon of interest should be gathered [4]. Action research is characterized by a desire to proactively investigate a relatively unexplored complex phenomenon (shared understanding) while solving a real-world problem. In a systematic cyclical process, the state of specific field situations should be understood and changed. Five phases are passed in an iterative, cyclical way, namely, diagnosis, action planning, action taking, evaluation, and specifying learning (see the section on the action research study for a description of all the phases).

In this paper, we follow the extended action research model by McKay and Marshall [38], who make a distinction between a research cycle and a problem-solving cycle. The two-cycle approach was chosen to address the dual goal of action research as well as to counteract the critique of lacking research rigor of action research. The research cycle aims at exploring the real-world phenomenon of interest to gain insights into the theoretical research framework. It leads to adding new knowledge to shared understanding theory. The problem-solving cycle aims at improving the specific real-world problem situation by using a problem-solving method to execute an intervention.

In the study reported here, the problem situation exists in the challenge of supporting experience-diverse work groups at a car manufacturing company to integrate and transfer their heterogeneous knowledge. The problem-solving cycle results in a collaboration process design containing the MindMerger compound thinkLet for shared understanding as the artifact that has been developed to change the real-world situation. If the problem situation is related to the phenomenon of interest and is suitable to explore the phenomenon of interest, both cycles can benefit from each other. In the section dedicated to the diagnosis of the research setting, we outline how the specific knowledge management challenge in our study qualifies as a suitable field for investigating shared understanding.

The dual approach is consistent with Briggs's [10] claim to separate theory building research from the specific artifact/technological instantiation by defining separate research and engineering questions. The action research design and findings are described in the following. The piloting project with six teams allowed executing six iterative cycles. This allowed us to iteratively develop the artifact—the collaboration process design containing the compound thinkLet—from findings of each of the six cycles. Simultaneously, insights on shared understanding could be accumulated from each cycle.

Collaboration Engineering as Design Approach for thinkLets

For developing the collaboration process and MindMerger as its core artifact, we followed the collaboration engineering design approach [30]. Collaboration engineering addresses the challenge of designing and deploying collaborative work practices for high-value recurring tasks and transferring them to practitioners to execute for themselves without the ongoing support from a professional collaboration expert [49]. As the construction of a shared understanding on ill-defined objects of knowledge is crucial for many collaborative tasks, high-value and recurring, it falls into the scope of collaboration engineering.

Much prior collaboration engineering research focuses on tasks, such as generation [16, 45, 46] or building consensus [2, 32], but little documented reusable procedures have been found on how to support the clarify pattern of collaboration (see the FastFocus thinkLet in [11] for a thinkLet aiming at clarification). Following Briggs et al. [14], to clarify means to "[m]ove from having less to having more shared understanding of concepts and of the words and phrases used to express them" [14, p. 122], and thus reflects processes for the construction of shared understanding. On the one hand, we use collaboration engineering methodology to split the task of building shared understanding into activities, and derive a compound thinkLet. On the other hand, we are gaining insights for the clarify pattern in collaboration engineering research by instantiating the MindMerger compound thinkLet in a real-world setting.

An Action Research Study to Develop and Validate a Compound thinkLet for Shared Understanding

Diagnosis of Research Setting

We were asked to improve the collaboration of experienced and inexperienced tool and dye makers as well as to increase the mutual knowledge transfer to ensure the retention of tacit knowledge within the organization independent of individual people. The organization is a large German car manufacturer. The goal was to build training manuscripts that would help inexperienced workers execute complex work tasks. As with many organizations, this company faces an increasing challenge to enable its members to integrate diverse knowledge. Longtime employees with great experience and deep understanding of the company's processes are confronted with unfamiliar rapid technological change in their work environment. When employees approach retirement age, the organization is endangered by losing the skills and tacit knowledge of these people if no appropriate means are in place to support the transfer of knowledge to new employees. New employees, however, bring an unbiased view of established work processes and recent technological education, but may lack the specific skills and expertise in highly complex fields. Young employees with recent educational knowledge and older, more experienced employees should be able to prevent critical knowledge from disappearing by learning from each other. Demographic change increases this challenge if only a small number of young technicians are qualified to fill the positions of a large proportion of experts within the workforce who are reaching retirement age. Both experienced and inexperienced group members need to understand each other's perspectives and converge on a shared understanding in order to work together effectively [5].

With respect to the outlined definition, shared understanding in this case refers to the degree to which the six members of one team concur on the work process steps (value of properties), the meaning of those steps (interpretation of concepts), and the order and relationship of the activities (mental models of cause and effect) with respect to the specific work processes they should document (object of understanding). Heterogeneity of group members becomes manifest in this setting in different dimensions, such as age, gender, formal education, work experience, and duration of association with the company (see Table 1). In particular, we paid attention to the equal staffing of each group concerning members with much versus little experience with the specific work task the group should document. Thirty-six workers participated in the project (5 females and 31 males). Experienced participants were, on average, 42.83 years old, inexperienced 23.06 years, the youngest participant being 19 years old and the oldest 57. Total job experience of the participants ranged from 5 weeks to 42 years. Each of the six groups was staffed with three experienced and three less-experienced workers concerning the specific work process.

Although other aspects are also involved, this practical problem situation is well qualified as an action research field to explore the general phenomenon of shared understanding and validate the compound thinkLet for several reasons. First, heterogeneity is a feature of the team staffing, and participants have not previously worked together on a similar task in this constellation. Therefore, initial shared understanding of the work process that should be documented can be expected to be low (due to heterogeneous experience) as well as shared understanding on how to build learning material (due to the lack of experience with similar workshops). Second, the challenges of knowledge transfer, retention, and generation at hand are closely related to team learning and shared understanding. Building a shared understanding on the object of the collaboration process early on may help accomplish the group goal. Third, work

Table 1. Demographics of Heterogeneous Participants

	Nonexperienced	Experienced	Overall
Gender			
Female	4	1	5
Male	14	17	32
Total	18	18	36
Age			
Min	19	23	19
Mean	23.06	42.83	32.94
Max	30	57	57
Job experience			
Min	0.1	1	0,1
Mean	5.3	23.25	14.53
Max	14	42	42

process documentation is a high-value and recurring task. With the MindMerger compound thinkLet at hand that is independent of the specific task, the process can be easily applied among others to similar knowledge management tasks.

Action Planning

In the action planning phase, the intervention to improve a problem situation is developed. We use the collaboration process design approach [31] to implement the goal (improve knowledge integration and shared understanding of a specific work process in the group while documenting the work process collaboratively) in a collaboration process design. We split the collaboration process into a series of three one-day workshops with homework activities in between the workshops. Only part of the first workshop is discussed in this paper, as these activities are dedicated to creating shared understanding of the sequence of activities required in the work process, and our focus here is on examining shared understanding. The collaboration sequence is characterized by three main phases: (1) an individual description (draft) of the craftsmen's work process, (2) integration of the individual drafts in pairs of two, and (3) the integration of the pair-wise drafts in one solution to which all six group members commit. In phase two and three, MindMerger is used twice.

Theory-Guided Activity Decomposition

Briggs [10] argues that grounding collaboration process design in good theory can enable unexpected success, as it can lead to nonintuitive design choices. Causal relationships described in theory provide designers of collaboration processes with hints for options they would not have considered without the theory. Good theory for design is hereby characterized by a model of causal effects, where the phenomenon of interest is the effect (in our case, shared understanding), which should be evoked by means of a design (in our case, the collaboration process). For many years the design of collaboration systems was considered more of an art than science, and successes or failures were hard to explain and repeat, as they were based on intuition and seat-of-the-pants reasoning [10]. It is the aim of collaboration engineering to develop predictable, reusable designs that support a class of recurring work practices. Thus, limited predictability and transferability of unsystematic approaches hinders the contribution of collaboration engineering work. Grounding collaboration system design in rigorous theory can help overcome these pitfalls, systematically improve collaboration research over time, and point to solutions that are not intuitive [10].

Taking the above into consideration, we used theory motivated design (see, e.g., [36]) to ground the design choices for the process on prior theoretical knowledge. In Van den Bossche et al.'s [48] model, each team learning behavior influencing shared understanding is reflected in two to four items. Each item was analyzed by Bittner and Leimeister [5] for its design implications. Every item from the model is reflected in at least one general design guideline (G1–10) (see Figure 1 and Table 2) from Bittner and Leimeister [5]. For example, design guideline 3 (ask questions for clarification) was derived from the item, "If something is unclear, we ask each other questions" to make sure that the design allows for a questioning phase on the individual conceptualizations.

The process design should reflect these aspects. We focus on these antecedents for the purpose of an initial design, conscious of the fact that future research should try to identify the underlying constructs that are changed by the observable behaviors in the model. For later design iterations, other or additional antecedents presented in the related work section might be considered. The design guidelines are used to split the task (constructing shared understanding) into a manageable and repeatable sequence of activities.

Design Artifact Documentation—the MindMerger Compound thinkLet for Shared Understanding

In this section, we present the MindMerger compound thinkLet design derived from the design guidelines through collaboration engineering in a generic way. Similar to established thinkLets [11, 33], the design should be reusable by other collaboration engineers, who can customize it to their specific collaboration settings and to their objects of shared understanding. The MindMerger compound thinkLet is characterized by two main phases: (1) an individual phase for revealing and documenting the understanding of each participant on the object of knowledge and (2) the integration of the individual drafts in pairs of two or larger groups into one document, to which all participants commit. This structure reflects the goal of a shared representation of the object of knowledge at the end of the execution of MindMerger. The individual phase is based on the assumption that an individual working space and individual reflection are critical, as members need to be aware of their own mental model. An individual representation should help by encouraging individual construction of knowledge and

Table 2. Theory-Based Design Guidelines

Determinant	Item	Design guideline
Construction	Team members are listening carefully to each other	G1: Express individual understandings first G2: Encourage members to try to understand each individual perspective
	If something is unclear, we ask each other questions	G3: Ask questions for clarification
Co-construction	Information from team members is complemented with information from other team members	G4: Collect individual descriptions in one shared place
	Team members elaborate on each other's information and ideas	G5: Evaluate understanding and consistency with own perspective
	Team members draw conclusions from the ideas that are discussed in the team	G6: Proceed on differences between understandings
Constructive conflict	In this team, I share all relevant information and ideas I have	G7: Encourage sharing of divergent views (parallel and anonymous)
	This team tends to handle differences of opinions by addressing them directly	G8: Address differences in discussion
	Comments on ideas are acted upon	G9: Process every conflicting aspect
	Opinions and ideas of team members are verified by asking each other critical questions	G10: Allow clarification questions and conflict negotiation

reflection as well as by serving as a boundary object and reminder of the aspects to discuss in the pairwise/group phase.

We recommend a pairwise phase to foster the interaction among participants with diverse knowledge. In a larger group the experienced members could easily take over the discussion and less-experienced or less-extroverted people might withdraw from contributing to the group product; in pairs of two, both participants are likely to be heard. This approach seems especially promising if the paired participants are very heterogeneous concerning their experience with the object of knowledge, their demographic characteristics, or their personalities.

The collaborative phase is further divided into three sequences according to the three learning mechanisms proposed by Van den Bossche et al. [48]. First, the participants try to make sense of the documents for themselves by reading their partner's structured description of the object of knowledge (activities A1–A3, Figure 2). Second, clarification questions are collected and answered to foster the co-construction of meaning and the evolution of mutual understanding (A4). A FreeBrainstorming thinkLet [11] was adapted to the special requirements of constructing individual understanding and mutual understanding on some object of knowledge. In particular, the new FreeConstruction thinkLet (see Appendix A) accounts for in-depth clarification of more complex conceptualizations of the object of knowledge rather than broad unrelated idea collections. Furthermore, switching pages is used to ask and answer clarification questions instead of elaborating on ideas as in a FreeBrainstorming.

However, mutual understanding is not sufficient for coordinated action toward a group goal, which should follow the MindMerger compound thinkLet. As the two drafts may still differ or even contradict each other in certain aspects, a third sequence of activities aims at evoking constructive conflict. Participants are asked to identify and resolve differences as well as conflicts in a discussion before integrating their drafts into one that both agree on. This procedure is represented in activities A5 to A8 (Figure 2), which include an adapted ReviewReflect thinkLet [11]. The major adaption—included in MindMerger—results from splitting the review phase into an activity for identifying differences and another for finding conflicts, before resolving both in a discussion. A detailed description of how the specific activities are grounded in the theoretical framework of the team learning behaviors can be found in Bittner and Leimeister [5]. Figure 2 shows MindMerger in a facilitation process model (FPM) notation. The individual activities are further detailed in Appendix A (thinkLets) and Appendix B (overall script and instructions).

Action Taking

In the action-taking phase, the planned intervention is executed in the field. The researcher interacts directly with the participants and actively gets involved in the changes introduced to the problem situation. For the problem-solving cycle, this means that the artifact—in our case, the collaboration process design with the MindMerger compound thinkLet for shared understanding—is pilot tested. Six pilot workshops were executed with groups of six tool and dye makers each. Each workshop lasted seven hours with a lunch break and several smaller breaks. Held in a university collaboration laboratory to release the participants from their daily routine, the workshops were moderated by one of the authors. Another collaboration engineering researcher facilitated and observed the workshop process. As the action research approach demands an iterative development of the solution, the full cycles were run through for every group, and necessary adjustments were made to the process design after each cycle.

Data for gaining new insights—into the problem field as well as into shared understanding as the phenomenon of interest—were collected throughout each cycle. A combination of different qualitative and quantitative data collection methods was used to ensure triangulation. Both the moderator and facilitator observed the group interaction and took field notes during and after each workshop. The participants were asked to fill out a standardized questionnaire before and after each workshop

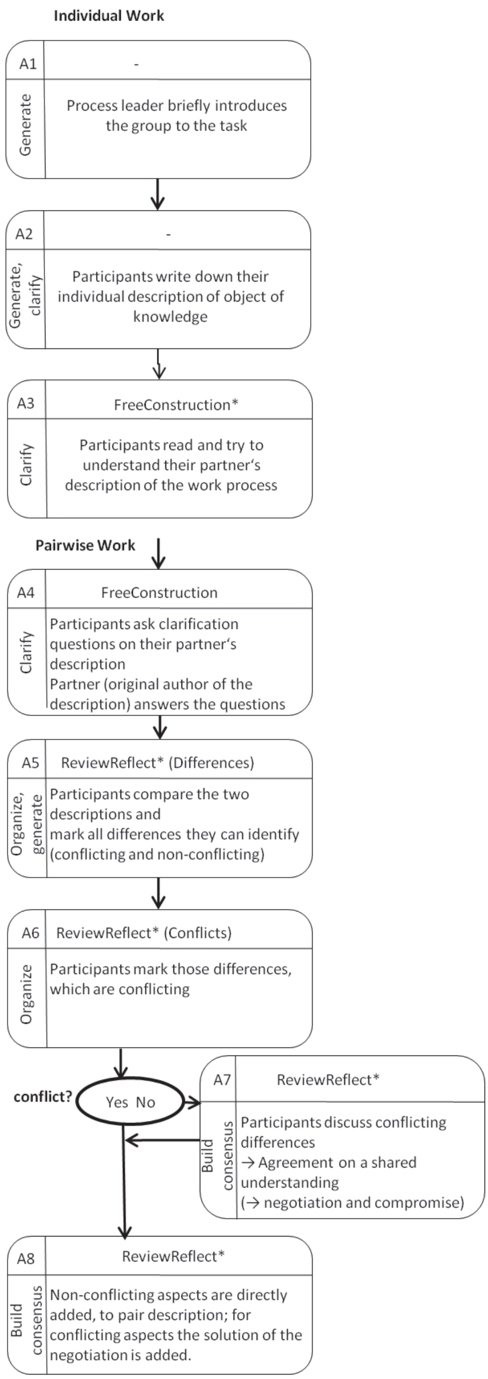

Figure 2. MindMerger—Facilitation Process Model (FPM) of Compound thinkLet for the Construction of Shared Understanding

Note: * Modified version of the ReviewReflect thinkLet, see Appendix A for adaptions.

for self-assessment of changes in (shared) understanding and team learning behaviors. The team learning behaviors were measured by the nine items in Table 2. In the questionnaires, demographic data were collected as well as process-related measures on perceived satisfaction and collaboration effectiveness. In addition, the group products—as they evolved during the process in the form of individual, pairwise, and group cognitive maps—were documented for further analysis. Cognitive maps resulted from the MindMerger execution. The participants wrote down work process steps on paper cards (one activity on each card) and sorted them in chronological order as they were executed in the work process (object of knowledge). Whenever parallel or alternative work streams were possible, additional cross-links were added. We present the results and insights in an aggregated manner in the following sections.

Evaluation

In the fourth phase of the action research cycle, it is evaluated whether the intervention had the intended effects and whether these effects were able to improve the problem situation. In particular, we examine if the participants showed the three group learning mechanisms (construction, co-construction, and constructive conflict) in the course of the collaborative process that the MindMerger compound thinkLet was meant to evoke. Furthermore, we analyze whether shared understanding increases throughout the process and how the mental model of the work process of the participants will change as they move toward joint representation. For the problem-solving cycle, the evaluation provides information on the extent to which the intervention has reached the goals set for the project, such as concerning knowledge transfer, group cohesion, or satisfaction of the participants. The practical evaluation provides an indication of the adjustments to the design that are necessary in the next problem-solving cycle as well as when the action research project can be closed. For the purpose of this paper, we focus on the evaluation for the research focus of the project. In addition to new knowledge on the research frame, insights into the phenomenon of interest are gathered. Every instantiation serves the advancement of the collaborative practices for building shared understanding in heterogeneous groups.

From a theoretical point of view, two major issues are addressed. First, it is of interest to ascertain whether the applied collaboration techniques were able to evoke the three team learning mechanisms (construction, co-construction, and constructive conflict), since they were identified as possible determinants for shared understanding. Table 3 shows the average values on all three learning behaviors on a seven-point Likert scale among all 36 participants that were measured using a German version of the nine items proposed by Van den Bossche et al. [48] (1 = "do not agree at all"; 7 = "fully agree"), which are listed in Table 2. All the constructs received very high ratings, significantly above the neutral value of 4 in a one-sample t-test (T), while no significant differences between experienced and inexperienced participants or between different teams could be detected.

Second, as the team learning behaviors are only a means to evoke shared understanding in the theoretical framework we use, the change in shared understanding has

Table 3. Team Learning Behaviors (Seven-Point Likert Response Format)

	Average	*N*	SD	T
Construction	6.3889	36	0.61075	23.468***
Co-construction	6.1481	36	0.66402	19.411***
Constructive conflict	5.9375	36	0.70553	16.477***

*** $p < 0.001$.

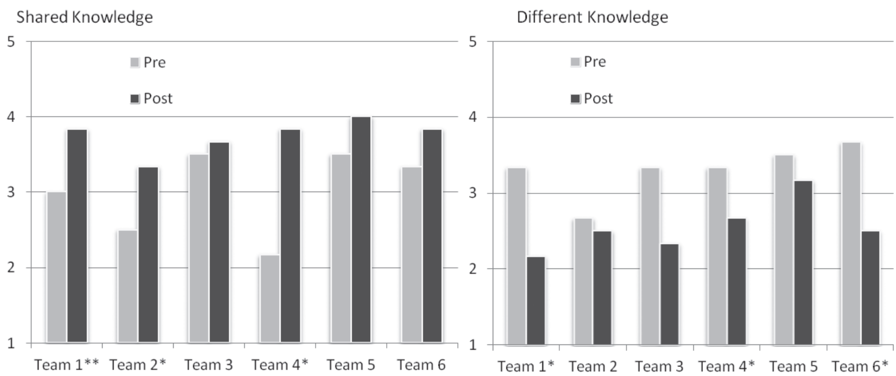

Figure 3. Changes of Shared Knowledge and Different Knowledge

** $p < 0.01$; * $p < 0.05$.

to be monitored and the effects of the techniques need to be assessed. We collected two self-assessment measures of shared understanding in a survey questionnaire at the beginning and the end of each workshop. Shared knowledge was assessed by the question, "To what extent does your group have similar knowledge on [name of the work task that should be documented]?" (1 = "none"; 5 = "very much"). Differences in knowledge were assessed by the question, "To what extent does your own knowledge on [name of the work task that should be documented] differ from the knowledge of your fellow team members?" (1 = "not at all"; 5 = "very much").

Figure 3 indicates that, although the teams started with different knowledge and different levels of perceived shared knowledge, all the teams experienced a substantial improvement of those measures. Table 4 shows how the measures for shared knowledge and different knowledge among the members of each group changed from pretest to posttest. Shared knowledge increased significantly from a mean of 3.0000 to 3.7500; differences of knowledge decreased from 3.3056 to 2.5556. This self-assessment of the participants is in line with our expectation that construction, co-construction, and constructive conflict in the collaboration process may be related to an increase of shared understanding. However, it must be noted that the scope and the goal of the explorative study were not to claim and test any causal relationships, but to gather rich insights into shared understanding and advance the compound thinkLet. For the sake of completeness, we explored the relation of shared understanding and team effective-

Table 4. Changes in Shared Knowledge and Different Knowledge (Five-Point Likert Response Format)

	Average	*N*	SD	Change	*T*
Shared knowledge					
Pre	3.0000	36	0.71714	0.75000	5.147***
Post	3.7500	36	0.64918		
Different knowledge					
Pre	3.3056	36	0.88864	–0.75000	4.652***
Post	2.5556	36	0.84327		

*** $p < 0.001$.

ness (as proposed by Van den Bossche et al. [48]). Under the conditions described in this study, we discovered a modest, yet interesting, correlation between shared understanding and measures of team effectiveness. Further research could be useful to more fully explore the nature of that relationship in other contexts and conditions. In this study, we used the variance-based partial least squares (PLS) approach to evaluate the proposed relationship of shared knowledge after the use of MindMerger with self-assessed team effectiveness after the completion of the whole workshop series. Different measurement points were used, as participants were expected to assess the team results better, when the process was completed and to avoid common method variance. The path-weighting scheme was used as a PLS algorithm with 300 iterations. The bootstrapping procedure was used to assess the significance of the path coefficient estimates. The number of bootstrap samples was 5.000. The results of the structural model indicated that the relationship is supported and significant at a level of 0.05. Team effectiveness showed a low level of explained variance with $R^2 = 0.312$.

As self-assessed changes in shared understanding may be biased and reflect only a perceived development, we used the changes in the work process documentation that the participants generated throughout the workshop as a complementary method to evaluate the evolution of shared understanding. Table 5 reports the number of unique activities mentioned in the work process documentation by each participant after activity A2 (Figure 2), pairwise after A8 (Figure 2), and group document, such as "retrieve data," and "roughen component." Furthermore, the increase (+) and decrease (–) in the number of constructs from individual to pairwise and from pairwise to groupwise documentation are displayed.

This evaluation is based on data from five teams, as we changed the form of process documentation after the first team to improve clarity and process smoothness, which hindered comparability of the documents. Because of the different work processes to be documented in the groups, deviations in the number and structure of concepts occurred and hindered quantitative between-group comparison. However, several trends became apparent. First, in most cases the number of constructs increased substantially from individual to pairwise to group documentation (Table 5). Even experienced participants who had been executing the work process for decades were not able to explicate and write down all the relevant process steps initially. New activities that had not been

Table 5. Changes in Shared Understanding—Number of Elements in Work Process Documentation. Experts (exp.) Versus Non-Experts (non-exp.)

	Individual	Pair-individual	Pair	Group-pair	Group
Group 2					
non-exp. 1	15	+ 42	57	+ 28	85
exp. 2	24	+ 33			
non-exp. 3	0	+ 70	70	+ 15	
exp. 4	15	+ 55			
non-exp. 5	12	+ 37	49	+ 36	
exp. 6	25	+ 24			
Group 3					
non-exp. 7	52	+ 18	70	+ 9	79
exp. 8	65	+ 5			
non-exp. 9	48	- 1	47	+ 32	
exp. 10	15	+ 32			
non-exp. 11	44	+ 22	66	+ 13	
exp. 12	55	+ 11			
Group 4					
non-exp. 13	29	+ 36	65	+ 22	87
exp. 14	49	+ 16			
non-exp. 15	17	+ 36	53	+ 34	
exp. 16	26	+ 27			
non-exp. 17	16	+ 22	38	+ 49	
exp. 18	36	+ 2			
Group 5					
non-exp. 19	57	+ 26	83	+ 23	106
exp. 20	80	+ 3			
non-exp. 21	39	+ 27	66	+ 40	
exp. 22	31	+ 35			
non-exp. 23	18	+ 46	64	+ 42	
exp. 24	54	+ 10			
Group 6					
non-exp. 25	60	+ 10	70	+ 13	83
exp. 26	65	+ 5			
non-exp. 27	54	+ 11	65	+ 18	
exp. 28	57	+ 8			
non-exp. 29	27	+ 23	50	+ 33	
exp. 30	28	+ 22			

mentioned by any individual came up in the construction, co-construction, and constructive conflict phases. This observation indicates that the team learning behaviors evoke mutual learning and that experienced participants can also benefit from the collaborative effort due to questioning and reflection. As participants showed commitment to their pair and group solutions, we came to the conclusion that the understanding of the work process became more detailed and elaborate throughout the workshops. A second trend is that in most pairs, the experienced participants (exp.) contributed more constructs initially, while their less-experienced coworkers (non-exp.) adopted more new constructs when a pairwise description was developed. In two pairs of groups three and five, the nonexpert contributed more than the expert. Both experienced participants noted in this situation that they found it hard to explicate their knowledge and that they benefitted from the comments and questions given by their colleagues. High values of pretest shared knowledge in both teams indicate that inexperienced members of those teams already had an idea of the work process—which could be verified in interaction with the experienced colleague, who was thus encouraged to divulge his knowledge [6]. Inexperienced participants generally started with a less detailed mental model of the work process, which was refined and complemented within the collaborative phases. Experienced participants held more advanced individual models, but gained further insights from the different documentation of their colleagues. They reported that the critical questions by inexperienced colleagues made them think about how to explicate and communicate their tacit knowledge. Some colleagues reported that the interaction made them aware of the existence of different approaches within their work group as well as of some activities they had forgotten to document. The formal evaluation concerning team learning was confirmed by oral reports by several participants, who had the impression that they had learned a lot from one another and that the group work had been helpful for their understanding.

Specifying Learning

Formally, the last phase of action research—the documentation and interpretation of findings—is, in fact, executed continually throughout the process. Knowledge that has been generated in the intervention and evaluation can be applied immediately in the diagnosis phase of the next cycle due to the open, exploratory research design. We gained insights into two major issues: the compound thinkLet design itself and the potential determinants for shared understanding for future theory building. Table 6 summarizes the main findings and the respective research cycles from which they resulted.

Lessons for the Compound thinkLet Design

Concerning the MindMerger design, only minor adaptions were necessary between the first two action research cycles. In particular, the initial participants documented their work process on flipchart sheets. As the participants frequently wanted to change the order of their sequence or wanted to insert further activities, later teams worked with individual paper cards for each activity in the work process. This visualization aid also proved better when pairwise and groupwise documentations were created, as it was easier for team members not only to ensure they had considered all the activities but also to note the saved time, as descriptions did not have to be built from scratch [6]. For the general thinkLet design and potential information technology support, this implies a need for flexible representation and visualization means. Depending on the

Table 6. Findings from the Action Research Cycles

Lessons for compound thinkLet design	Resulted from cycle
Individual phase critical for reflection/explication of understanding	2, 3, 5
Dynamic map representation of mental model rather than static list	1
Visualization/haptic boundary objects to support interaction	1, 3
Reflection on specific marked differences of understanding easier than assessment on a global level	1
Lessons for shared understanding (SU) theory	
SU definition should cover value of properties, interpretation of concepts, and mental models of cause and effect	1–6
Team learning behaviors seem to occur and can be evoked by design	1–6
Role of boundary objects and visualizations for SU needs exploration	1, 4
Ideal degree of SU needs exploration	1–6
Ideal degree of heterogeneity in teams needs exploration	4–6
Potential constructs underlying construction: awareness for own understanding and visualization of individual maps	1, 3, 5, 6
Potential constructs underlying co-construction: prior mental models, prior heterogeneity	1–6
Constructive conflict similar to negotiation/building consensus pattern of collaboration	1–6

object of knowledge, the workspace or group support system needs to enable participants to express elements and relations of their mental model in a well-arranged way. This finding is in line with our definition of shared understanding. Issues of diverse understanding appeared to occur on different levels (information, meaning, and mental models). Representations of knowledge should reflect all of those levels.

The second process adaption concerned an evaluation activity initially executed after the pairwise phase, but was left out in the revised design. Participants had been asked to reflect on the differences of their own pair's documentation in comparison to the other two. On a Likert scale the participants indicated how much their documentation conflicted with their own understanding of the work process. It turned out that this global level of evaluation did not provide any benefit for the collaboration process; furthermore, we could not identify a recognizable impact on further discussions, and it was thus omitted [6]. For the general thinkLet design, we noted that discussions on very specific differences or conflicts in understanding that were marked in the documents were more effective in leading to changes in the cognitive maps than were discussions on the global work process. Especially for complex objects of knowledge, we thus propose the map-like representation.

In further iterations, no major changes to the design had to be made. We observed that all teams acted in a relatively similar manner and followed the process design. Evaluation indicates that team learning behaviors could be evoked in every group, and measures of shared understanding developed positively. Although generalizability is limited by the application in only one type of collaboration process, stable observations in all six teams suggests a good reproducibility of the MindMerger process and results. The increases in shared understanding measures and the occurrence of team learning behaviors indicate that the thinkLet may be a beneficial design module to evoke the clarify pattern.

Lessons for Shared Understanding Theory

Concerning shared understanding theory, we observed that the findings from the validation study were consistent with our definition of shared understanding. We were able to provide a definition of shared understanding that matches issues of shared understanding related to (1) the value of properties, (2) the interpretation of concepts, and (3) the mental models of cause and effect with respect to an object of understanding. Clarification could be observed on all three categories when action research participants developed joint concept maps of their work processes. Some pairs discussed, for example: (1) what the correct values for a machine set-up in a specific setting were; (2) others converged on a joint definition of what activities a certain name of a work process step covers and what it does not include; and (3) changes in the order of work process steps from the individual to joint concept maps up to complex tree structures indicated that mental models on a more structural level converged as well.

For the exploration of determinants of shared understanding, the empirical evaluation showed that the three team learning behaviors were reported in the questionnaires of all six groups after the use of the MindMerger compound thinkLet. This provides an indication that the MindMerger design seems to evoke those mechanisms. In combination with a rise in shared understanding indicators from pre-intervention to post-intervention, we conclude that our study results are consistent with Van den Bossche et al.'s [48] proposed model. However, from the literature overview and the observation of interactions within the groups, we identified a need to investigate other potential determinants in future studies. In particular, the role of boundary objects and visual explication of mental models deserves deeper consideration. We noted that participants proactively used objects from their surroundings (boxes, pens, etc.) to demonstrate certain work processes and referred strongly to the elements in the explicated concept map when discussing issues of understanding.

Furthermore, we encountered some limitations of the theoretical model that guided our design. Team learning behaviors could be observed and measured by self-assessment, but the constructs underlying these behaviors are still unknown. Concerning construction of knowledge, awareness of one's own individual understanding (value of properties, interpretation of concepts, and the mental models of cause and effect) may be one of the core constructs of interest that should be further investigated. This assumption is based on the observation that several participants expressed an initial difficulty of recalling and explicating all elements of their work process and the order of the activities they regularly performed. Thus, one determinant of shared understanding development—which is evoked by construction—might be the awareness for one's own understanding of a certain object of knowledge. A second potential construct underlying construction may be availability and accessibility of a detailed (visual) representation of the individual mental model for sense-making by others. The more detailed the initial individual concept maps were, the more elaborate joint concept maps were developed by the pairs.

For the co-construction behavior, potential underlying constructs are related to the degree to which certain aspects of knowledge that are new to the group members can be related to their existing knowledge frames. This perspective should be investigated in light of existing knowledge on constructive learning theory [43, 50]. We observed that the teams within which all members had at least encountered the specific work process in practice once or twice found it easier to build, combine, and extend rich representations of their mental models. Teams with complete newbies or an unfamiliar external observer asking questions reported, however, that the interaction challenged the experts' established views on the process. We conclude that a maximum level of shared understanding might not in all cases be the optimal state. High heterogeneity—coming with a low level of initial shared understanding—might even foster team effectiveness in creative nonstandard tasks. Optimal team staffing in light of aspired initial and target shared understanding thus deserves further consideration in future work and managerial practice, as it might impact the relation of shared understanding and team effectiveness.

Issues related to the constructive conflict behavior are very much related to negotiating a joint perspective. Future research on the constructs associated with moving from mutual to shared understanding should thus try to build on theoretical work in related disciplines (e.g., on the build commitment pattern of collaboration) or from group negotiation research.

Implications, Limitations, and Future Research

Contributions for Collaboration Engineering Research and Practice

The main contribution of this paper for collaboration engineering practice is a validated compound thinkLet for shared understanding (Appendix B). This collaboration process module should be used by designers of collaborative work practices to systematically and repeatedly induce the development of shared understanding in heterogeneous groups. The MindMerger compound thinkLet involves a distinct and novel sequence of collaborative activities, which are designed to evoke behavioral and cognitive processes leading to shared understanding. Thus, the MindMerger makes use of established thinkLets, while adding a combination of collaborative procedures that have been identified as critical to shared understanding development, such as individual construction and reflection followed by collaborative identification of differences in understanding. Our validation in the action research study provides an indication that MindMerger may help to evoke team learning behaviors and increase shared understanding among diverse group members. As shared understanding has been identified as crucial for collaboration success in heterogeneous groups, the compound thinkLet may foster better group processes and better results. As it is documented in a detailed thinkLet form, the MindMerger compound thinkLet can easily be applied to similar knowledge management tasks as well as to other collaborative settings where building a shared understanding early on is critical, such as in newly formed distributed online project teams. We furthermore contribute to collaboration engineering research with a deeper understanding of the thus far underresearched clarify pattern. Informed by research from related disciplines and the findings from the usage of the MindMerger compound thinkLet in a practical application, we discussed starting points for further collaboration engineering research. In particular, MindMerger should be applied to alternative practical collaboration situations with heterogeneous actors (e.g., requirements negotiation, design projects, strategy workshops) and tested in controlled experimental settings to overcome limitations due to the action research design. Due to the technology-independent thinkLet description, instantiations with different forms of technological support (e.g., group support systems, online collaboration platforms) can easily be explored. In addition, our exploration of potential determinants and effects as well as the conceptualization of shared understanding can serve as a starting point for developing more clarify thinkLets and for theorizing on an explanatory model of shared understanding.

Contribution to Group Cognition Research

With this paper, we provide a definition of shared understanding that builds on a review of the diverse field of previous conceptualizations. By defining three categories of domains for shared understanding, this definition contributes to clarify the thus far fuzzy construct shared understanding. While we used existing measurement items for shared understanding for our survey combined with open exploration, a need is revealed for more advanced measurement instruments that allow all three categories of shared understanding to be identified. The definition of shared understanding implies that measurement needs to account for gradual changes to the concurrence of the value of properties, the interpretation of concepts, and the mental models of cause and effect with respect to an object of understanding. In addition, we were the first to apply Van den Bossche et al.'s model [48] of team learning behaviors to a real-world collaboration process. Our findings support the relationships proposed by the model in this real-world case, although we argue for future refinement of the model with its underlying constructs, including, for instance, potential roles of boundary objects, the interplay of different degrees of heterogeneity and shared understanding, or different types of visualization used during the team learning activities.

Limitations and Future Research

The exploratory action research design poses some limitations on the findings, which should be targeted in future research. No definite conclusions on cause-and-effect chains between the compound thinkLet use, team learning behaviors, shared understanding, and team effectiveness could be drawn, although findings were consistent over all the groups. The action research setting allows holistic observation of realistic collaborative interaction. However, additional evaluation of the compound thinkLet and proposed theoretical relationships in an experimental setting with control groups who collaborate without the treatment will be necessary. Future research should furthermore transfer the design to practitioners to test for one of the major goals of collaboration engineering, execution by practitioners with reproducible results [15]. The MindMerger compound thinkLet was able to lead to stable results in this study. Application in other areas of heterogeneous groups (e.g., requirements negotiation [25], strategy workshops, design projects) should further prove its generalizability and value for practice. Finally, when it comes to the important relation of heterogeneity and shared understanding, the optimal degree of heterogeneity in a group with respect to its ability to build a shared understanding deserves exploration, as well as the optimal degree of shared understanding a group should have on a certain object of understanding in order to collaborate effectively but maintain the benefits of diversity.

Conclusion

We present a definition and conceptualization of shared understanding covering different facets of this fuzzy construct. Consequently, we derive a theory-motivated design of the new MindMerger compound thinkLet using collaboration engineering and validate it iteratively in a large-scale action research project. Following a design research paradigm, we thus contribute to solving an important class of practical problems (integrating diverse perspectives of multiple actors in heterogeneous groups) while adding new insights to the knowledge base on shared understanding. The validated compound thinkLet provides designers of collaborative work practices with a reusable module of activities to solve clarification issues in group work early on. Findings from the field indicate that mechanisms for shared understanding can be systematically evoked by our collaboration design. Although the results of this study are stable and promising, we identify a need for further investigation of mechanisms leading to shared understanding. Thus, future research should aim at better understanding the complex phenomenon, its antecedents and effects, thus generating more promising opportunities for developing more techniques to leverage the benefits of shared understanding for effective group work. We believe that organizations can use the results of this study to improve their group performance, especially in heterogeneous groups.

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Appendix A: thinkLets Used in the MindMerger Compound thinkLet

FreeConstruction (adapted from Free Brainstorm [11])

Choose this thinkLet . . .

. . . to cause the group to diverge quickly from comfortable patterns of thinking, to push them farther and farther afield in search of new ideas.

. . . to eliminate influences of other team members' mental models at an early stage of reflection.

… to cause team members to reflect deeply on their individual understanding of an object of knowledge and express it.

. . . to cause team members with narrow, parochial views to quickly see the big picture, to quickly create a shared vision in a new, heterogeneous team.

Do not choose this thinkLet . . .

. . . if you are pushing for breadth of unrelated ideas rather than depth in the resulting ideas, consider using FreeBrainstorm instead.

Overview

In this thinkLet, the team members construct conceptualizations of a single object of knowledge. The team members are working on separate pages that are circulating among them. They try to make sense of each other's conceptualizations.

Outputs

One page of structured conceptualization on the object of knowledge provided by each team member which is understood by all team members.

How to use FreeConstruction

Setup

1. Create construction pages (paper based or electronic): one page for each participating team member.
2. Enter the construction question (on the object of knowledge).

Steps

1. Say this:
   a. Please go to your individual construction page.
   b. You will each start on a different page.
   c. You may each sketch your understanding of the [object of knowledge]. Visualize the elements of [object of knowledge] as well as their relations, after which you must send the page back to the group.
   d. You will randomly be provided with a different page.
2. That page will have somebody else's sketch on it. Please read it and try to understand it.
3. When you see a page with someone else's or your own sketch on it, you may respond in three ways:
   e. If you fully understand a sketch → send it back to the group
   f. If you do not understand certain aspects of the sketch → mark them and contribute a clarification question for each aspect → send it back to the group
   g. If you see your own sketch → answer all open clarification questions posted → send it back to the group
4. After sending your contribution, the system will bring you to a new page. We will continue swapping pages and submitting questions and answers (until no unanswered clarification questions are open).

Any questions? You may begin.

Modified ReviewReflect

Choose this thinkLet . . .

. . . when you must review, validate, and modify the content of an existing outline or other information structure.

Do not choose this thinkLet . . .

. . . when you need to generate an information structure from scratch. Consider using the BranchBuilder thinkLet instead.

Overview

In this thinkLet you adapt an existing generic text to the needs of the task at hand, or you review and comment on a deliverable document. Some thinking tasks jump off from existing content. For example, a team in an automobile factory might begin a risk assessment by considering a list of standard risks for the automobile industry. The ReviewReflect thinkLet is a way to review and tailor the existing content into something more useful for the task at hand. The thinkLet proceeds in two passes. In the first pass, all participants review and comment on the existing content. In the second pass, the participants negotiate the restructuring and rewording of the content.

Inputs

Preexisting content in the form of a list, outline, or other document.

Outputs

A revised document that more closely meets the needs of the task at hand.

How to use ReviewReflect

1. Post the existing outlines.
2. Configure the tool so that comments can be annotated to each element of the outline.
3. Say this:
   a. Please read each aspect of this outline and reflect about whether it is (different/conflicting) from your understanding of the [object of knowledge].
   b. If you find something on the outline that differs from/conflicts with your version of it, mark it and explain why.
   c. When we are finished, we will revise the outline based on your comments.
4. Allow all users to review, reflect, and comment on the outline simultaneously.
   Open a new document for a joint outline. Go through all outline elements. If you . . .
   a. . . . find an outline element that has no marks and comments → add this to the joint outline directly.
   b. . . . find an outline element that has "difference" marks on it → read the comments and say: We have several "difference" marks on this element of the outline. This means the element occurs in only some of the outlines or occurs in the outlines in different ways. Should we transfer this element to the joint outline or not?
   c. . . . find an outline element that has "conflict" marks on it → read the comments and say: We have several "conflict" marks on this element of the outline. This means you need to find an agreement on how to treat this element. Please make a suggestion.

5. Moderate an oral discussion. Revise the joint outline as directed by the group.
6. Repeat steps 3 through 6 until all comments have been addressed.

Appendix B: Overall Script and Instructions

MindMerger: Compound thinkLet for Shared Understanding

Goal

Clarification: Move groups from a state of less shared understanding to more shared understanding of a certain object

Deliverable

Increased the degree of SU on the object of knowledge (to enable group to work more effectively afterward)

Participants

Six participants per group:

- 3 experienced/knowledgeable concerning the object of interest
- 3 inexperienced/newbies concerning the object of interest

Target Participants

Participants who are heterogeneous in their understanding of the object of knowledge, e.g., due to their demographics, training, attitude, or experience.

Preparation

Specify the object of knowledge and insert in placeholders

For A2: Delete questions for processes or tasks/concepts (depending on the object)

Agenda

A1 (5 minute): Introduction

(–) [PowerPoint Slides]

Say this: Thanks for coming.

Introduce yourself and the facilitator.

Present the goal of the process, frame the object of interest (e.g., task, work process, team structure, or technology).

Say this: We'll first work individually, then in pairs and finally with the whole group. We'll use paper cards to document the structure of [object]. The session will last ____.

A2 (15 minutes): Individual construction of meaning on the object of interest
(Step 1 of FreeConstruction) (paper cards)

Say this: For processes: Please write down the process steps that need to be executed to achieve [object]. Sort the process steps chronologically in the order of their execution.

Say this: For tasks/concepts: Please write down all aspects that characterize [object]. Sort the aspects as they relate to each other.

Say this: Note: Please be as specific as you can about the concepts you write down so that the other participants can understand each concept by reading. Please use one card for each concept.

Transition (3 minutes)
Take a photo of each card map. Ask participants to take their cards. Announce pairs (one experienced + one inexperienced participant each). Send pairs with instruction sheets to their separate workspace.

A3 (5 minutes): Pairwise construction of meaning
(Step 2 of FreeConstruction) (Paper cards, whiteboard)

Say this: Try to understand the concepts and structure your partner used. Why and how did he conceptualize [object] in a potentially different way than you did?

A4 (15 minutes): Pairwise clarification of different understandings
(Step 3 of FreeConstruction) (Paper cards, sticky notes)

Say this: (a) Please read through your partner's card map individually. Which cards don't you understand? Which relationships/orders don't you understand? Please mark every card or relationship that you would like to ask a clarification question on.

Say this: Note: Please collect only questions at this point of time. There will be time to discuss your questions with your partner soon.

Say this: (b) For the first map: Please ask your clarification question for each of the markers. Please answer your partner's clarification questions. Remove the markers for each answered question and add extra descriptions to the individual map where they help to clarify.

Say this: Repeat (b) with the second map.

Step 4 of FreeConstruction will only be executed in the second round of FreeConstruct, when 3 maps need to be matched.

A5 (5 minutes): Awareness of divergent views
(Modified ReviewReflect) (Paper cards, sticky notes)

Say this: Please compare both your concept maps with your partner. Which differences can you identify?

Say this: Note: Please mark all concepts and relationships that only occur in one of the two maps that should be represented in your pairwise map.

A6 (5 minutes): Identify conflicts

(Modified ReviewReflect) (Paper cards, sticky notes)

Say this: Which conflicts need to be resolved?

Say this: Note: Please mark all conflicts between the two maps (conflicting concepts, wording, relationships, and order) that need to be resolved when you need to agree on one joint representation that you want to present to the group. Collect only differences and conflicts, as you will have time to search for solutions afterwards.

A7 (20 minutes): Create joint concept map

(Modified ReviewReflect) (Paper cards, sticky notes)

Say this: Please go through all of the cards together. Take one of the following actions:

a. If a card with the same concept exists in both maps, add both to the joint map as one concept
b. If a card is marked as "different" (occurring in only one map), discuss its place in the joint map and place it there
c. If a card is marked as conflicting, discuss which version you would like to use in the joint map
d. If a relationship is marked as conflicting, discuss which order/relationship you would like to transfer to the joint map

Transition (5 minutes)

Say this: Finalize your joint map. Prepare to present your joint concept map.

A8: Groupwise construction of meaning (second iteration of A3–A7)

(–) (Paper cards, whiteboard)

Each pair of participants presents their concept map to the group. The group tries to understand the other maps.

Say this: Try to understand the concepts and structure the other pairs used. Why and how did they conceptualize [object] in a potentially different way than you did?

Repeat activities A4 to A7 with the whole group of 6 participants.