Cognitive Load in Collaboration - Convergence

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Abstract

Collaboration is inherent to complex participatory multi-actor and multi-agent social technical systems. Supporting collaboration is challenging. One of the key production factors in collaboration is cognitive effort. Understanding cognitive load involved in collaborative tasks is therefore important to the design of collaboration support. This paper focuses on cognitive load related to convergence, a very complex collaborative task, that is much less studied than the often preceding, divergence or brainstorming task. On the basis of an overview of convergence techniques, and literature on convergence this paper presents a framework for the assessment of cognitive load during collaboration processes, and strategies to deal with cognitive load in convergence. The paper ends with a reflection on the use and implications of the framework.

1. Introduction

Collaboration is a sine qua non for innovation and productivity of organizations[1]. Knowledge intensive collaborative tasks often require high cognitive effort. Collaboration implies a team to perform a task jointly, thus requiring interaction and coordination of cognitive effort[2]. Coordination and support of collaboration can be offered by a group member (leader), or by an external facilitator or mediator. Furthermore, tools and training can offer guidance in collaborative activities [3]. Cognitive load is typically higher for collaborative tasks then for individual tasks [2], and therefore groups often benefit from tools and facilitation to structure their cognitive effort[4]. Examples of such tools are social software, workshops, facilitated (electronic) meetings or discussions, and Group Support Systems.

Cognitive load is the cognitive effort made by a person, required to perform a task [5]. Cognitive load theory (CLT) distinguishes various design principles to efficiently and effectively use cognitive capacity [5] in the context of learning. However, in the context of collaboration support, less research is devoted to understanding the cognitive implications of process and technology design.

Recently scholars have indicated that the cognitive perspective on collaboration requires further research, because it is the key to resolve paradoxes in research findings with respect to the use of collaboration support [6]. To gain an understanding of the effect of interventions in collaborative effort (made though collaboration support) and to resolve the conflicting findings with respect to the effects of collaboration support, interventions in collaboration need to be studied in more detail, with a focus on cognitive effects of these interventions [6, 7].

To design interventions that improve cognitive efficiency and effectiveness and reduce the demand on the central executive in collaborative tasks requires an understanding of cognitive activities and processes in collaboration. This paper presents first steps in developing a framework for assessment of cognitive load in a collaboration context. Based on literature and examples of existing collaboration support techniques and tools the role and design implications of cognitive load in the convergence phase of collaborative problem solving tasks are explored. Initial validation of the framework is offered though evaluation by four expert facilitators.

2. Cognitive Load

Cognitive load can be defined as the cognitive effort made by a person to understand and perform his/her task [8]. Cognitive load has both a task-based dimension (mental load) and a person-based dimension (mental effort) [5, 9]. The task based load, further has a perceptual and a cognitive dimension, related to the amount of information presented, and the amount of information that needs to be processed in the working memory [10]. The concept of cognitive load in cognitive load theory is associated with the seminal assumption that our short-term or working memory, also called central executive is limited [11-13]. The central executive in this theoretical model is a simplification of the various parts of the brain that are involved in cognitive processing of information. Problem solving tasks are mainly associated with the prefrontal cortex, which is also used to recall things from memory and to inhibit distraction [14]. While cognitive- and neuropsychologists offer ample debate on the different ways in which cognitive tasks are performed in the brain, they agree that our capacity to process information is limited, and that these limitations are actively experienced in problem solving tasks [14]. Furthermore, research in instructional design has shown
ample evidence that the way in which information is offered and structured has significant effects on performance in problem solving [8].

Besides short-term memory, the theory also assumes people have a long-term memory, which stores large quantities of information, in so called schemata [8]. Information in long term memory is related, networked or associated in these schemata [14]. Through a process called automation, and also called chunking [11, 12], larger schema can be used in the working memory as a single component, allowing the processing of more complex information. Problem solving is a complex task, and can benefit from support. Early research from Simon et al already indicated that we can learn a lot about problem solving and how to support it, when looking at it from a cognitive perspective [15]. Cognitive overload causes effects such as impaired performance and decision making, stress, difficulty to retrieve knowledge, impeding creativity, and difficulty to analyse and organize knowledge, impeding schema building and learning [16]. Solutions to cognitive overload are amongst others to plan and regulate information flow, to structure information and to use intelligent agents to analyse and filter information [16]. Cognitive overload is ineffective, but too low cognitive load can also be ineffective as it leaves cognitive capacity for distraction, which can then take attention away from the task. The cognitive load of a task differs for each individual, depending on their experience in the domain and skill in the type of problem solving task [17, 18]. Furthermore, people can get distracted while performing a task, or use an ineffective way to process the information due to fatigue or lack of skill [14].

Cognitive load theory (CLT) in the context of learning explains how cognitive capacity is used to construct schemata and use them for problem solving tasks. Three types of cognitive load [8] are distinguished:

- Intrinsic cognitive load is the cognitive load that is inherent to the task, defined by the intrinsic task complexity.
- Extraneous cognitive load is the cognitive load caused by the presentation and transition method of the information. Extraneous load should be reduced as much as possible, as it is ineffective. However, it cannot be completely eliminated.
- Germene cognitive load is the cognitive load instrumental to building schemata and storing them in the long term memory. For learning, germe load should be stimulated.

Limiting unproductive mental activity is a critical challenge for information systems [19], particularly those that support collaboration and collaborative effort. CLT provides different methods to reduce extraneous cognitive load such as providing parsimonious information elements, avoiding split attention by disintegrated or unstructured information [5]. The same holds for intrinsic cognitive load that is directly related to task complexity. Pollock et al [20], propose that the intrinsic cognitive load can be reduced for by pre-structuring complex information. By pre-structuring the information, it can be absorbed in parts (requiring less cognitive effort) that are meaningfully connected, which facilitates schema building [16]. Also research has reported initial results on stimulating learners explicitly to construct and automate schema, increasing productive germane load [21]. CLT has provided new insights in instructional design improving learning efficiency and effectiveness.

In collaboration, cognitive load has many sources. It can originate from the information shared among participants through various communication channels, from constructing and thinking up new information, from explaining or arguing positions, from assessing value, implications and effects of decisions, from various procedures, and from distractions. In previous work we explored cognitive load involved in brainstorming [22]. In the next section cognitive load in a difficult cognitive task: convergence will be explored.

3. Convergence

When groups collaborate they often go through a goal oriented problem solving or design process with roughly three phases; they diverge to gather, share or brainstorm information. Second, they analyze and converge the information available to create meaning and shared understanding. Third, they make decisions based on the information analyzed. This paper focuses on convergence; the process of analyzing and organizing the information shared in a group. Divergence (also called generation or brainstorming) [23] often produces a large volume of content of varying relevance, across multiple levels of abstraction and of varying granularity. This knowledge, shared and created by a group, needs to be converged to a manageable size, to create an overview of its content, to be used for further analysis, evaluation or decision making. There are many ways to approach convergence, and there are significant differences in the cognitive effort they require, and the rigor with which the convergence is achieved. Typically, the goal of convergence is not yet to choose among alternatives, rather it is to create a parsimonious overview of alternatives. However, we acknowledge that some judgment or evaluation is likely to happen as ‘out of scope’ alternatives could be removed, similar alternatives can be merged, and strategic behavior can occur in this process. Furthermore, convergence activities can give rise to new ideas, and consequently causing ideation and divergence. The exclusive focus in this paper on convergence is to scope the paper. For a full collaboration process design, cognitive activities in brainstorming and evaluation should also be considered.

We decompose the convergence process in six phases. First there is a preparation phase in which the group

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familiarizes itself with the convergence task, next the group analyses the set of contributions for convergence. After analysis contributions are actually converged; clarified, integrated or related. The next phase involves reflection on the implications of individual convergence activities, possibly leading to further convergence or adjustment of convergence. Furthermore there is overall reflection. Once the converged set of information has taken shape, the total set is re-considered for overall quality. Again this can lead back to convergence and analysis activities. Finally the group can be distracted in their activity, which is a ‘phase’ parallel to the other phases.

Convergence has three key aspects: (1) creating shared understanding, (2) eliminating redundancy, similarity and overlap, and (3) creating overview and structure in a set of contributions by identifying relations among contributions [24, 25]. Not all convergence processes focus on all three aspects, teams might initially have a good shared understanding, or they might have structured their brainstorm session effectively, diminishing the need for organizing in the convergence phase.

3.1 Clarify for shared understanding

To create shared understanding, entails; creating shared meaning of language symbols and labels, resolving asymmetry of information and resolving differences in mental models [26]. Mulder, Swaak, & Kessels [27] explain the notion of shared understanding as mutual knowledge, mutual beliefs, and mutual assumptions. Groups achieve shared understanding when they come to a common understanding of concepts and words that are related to the task at hand.

Sense making is done to prepare a group to act in a principled, and informed manner [28]. Sense-making tasks often involve searching for contributions from others in a group that are relevant for the purpose at hand and then extracting and reformulating the information so that it can be used [29]. Note that sense-making requires more than shared understanding of concepts and terms; it also requires a common understanding of a shared problem, its context, and possible solutions.

3.2 Reduction, abstraction or filtering

The next phase in convergence is to reduce the actual amount of information considered, the knowledge shared and created in a group. A group can choose to select key concepts. Two approaches to selection are distinguished. First a group can filter information; each piece of information is considered and kept, adjusted or discarded, to reduce redundancy and increase consistency. Second, a group can choose an approach where key concepts are identified and selected from the pool of information considered by the group (cherry picking). In this case, information that meets e.g. the criteria of fit and consistent are selected.

A second approach to reduction is a form of summarization. Rather than filtering, the aim of this approach is not to select part of the information, but rather to capture the essence of information with fewer information elements. Redundant information is removed; but no choices are made with regard to which remaining information is preferred over other information.

There are several approaches to summarizing. First, summarizing can be accomplished by selecting only unique information. Second, similar contributions can be merged, to keep only unique information. Third, an instance of similar pieces of information can be selected to represent multiple instances. Last, extraction of the most important information can also be used as a summarizing method [30].

A third approach to reduction is to reduce information through abstraction. The purpose of abstraction is to make content more intellectually manageable by allowing group members to pay attention to relevant information and to ignore other details. Smith et al. [31] describe two approaches for abstraction: generalization and aggregation. Generalization refers to an abstraction in which a set of similar objects is regarded to be of a specific generic type/object, aggregation refers to an abstraction in a hierarchical relationship between objects.

The difference between summarizing and abstraction is that in summarizing the same information is represented with fewer information elements while in abstraction information is characterized by higher level concepts that encompass relevant information in the original set.

3.3 Organizing or structuring

Finally, a group can choose to identify and document relations among contributions in order to structure the information, to make it easier to store in memory, and to create an overview of the knowledge for analysis and decision making. Creating such structure can be done by relating information. The most common relations are abstraction to identify hierarchical relations and sequencing to create temporal relations [32]. Further, groups can create causal relations to describe cause and effect. Categorization, sometimes referred to as classification, is the most common form of organize [33], and is often used as a step after brainstorming. A similar activity is performed in the creation of a shared ontology [34], in which shared meaning is created of concepts and their relations.

Sequencing is mainly found in scheduling, planning, workflow and project management [35, 36]. Causal modeling in collaborative setting is researched in Group Model Building literature [37, 38] and in soft systems
methodology (strategic options development and analysis) [39]. Causal relations are often more complex for participants to understand, and many of these approaches prescribe the role of a modeler to support the group in capturing relations and guarding consistency. Another approach is to use shared task and decision modeling [40].

In convergence tasks, especially for organizing visualization is intuitively used to reduce cognitive load. Complex concepts and contributions are often visualized to explain and convey them to others. Visualization can be any style of capturing information for all to see, from writing/typing to drawing to modelling. This is especially the case in modelling, where often nodes and their relations are visualized in a specific language. Research has indicated that visual attention is competitive; on can only hold on to one or a few mental images given our limited cognitive capacity. Therefore, it is very difficult for people to understand someone else’s visualization. This makes collaborative modelling particularly challenging, as it will require people to be open minded to visualizations of others, and to switch between their own visualization and those of others.

4. Cognitive Load of Convergence

To create an overview of cognitive activities in convergence this paper focuses on ten convergence ThinkLets. ThinkLets capture best practices in patterns of collaboration [41-43]. The thinkLets used are: CheckMark, StakeholdersPoll, Relate-it, Evolution, FastFocus, BucketWalk, PopcornSort, Concentration, Goldminer and ThemeSeeker, as documented in [44].

One of the authors has facilitated over a hundred workshops in education and industry settings based on thinkLets, including the listed convergence thinkLets, and thus has experience in conducting these techniques. ThinkLets are documented as scripts and prescribe how to facilitate a collaborative activity. For each thinkLet this paper identifies the cognitive activities required to perform the thinkLet, and lists these in a table. Overlap of cognitive activities was then identified and removed.

Next, cognitive activities are grouped in the convergence phases to create a complete list. The resulting set of cognitive activities are compared to the convergence aspects found in the literature described above, to verify completeness of the convergence activities. This completeness check also considers basic cognitive activities; understand, decide, recall (from memory), memorize (store in memory) and inhibit (to push away distracting thoughts or stimuli) [14]. In this way an overview of the cognitive activities in collaborative convergence is created, which we will then classify based on their effectiveness.

Effectiveness of convergence depends on the context of the problem solving task; it can create reduced complexity, shared understanding, and overview (interrelatedness, system) of the shared information, which might be more or less required depending on the task, group and experience of group members. We can classify cognitive activities to a convergence goal, based on which the extent to which they are effective (on-task load) or ineffective (off-task load). Also we distinguish cognitive effort that is required for the process, but not directly effective, similar to the ‘extraneous cognitive load’ in instructional design.

The overview of the cognitive processes involved in convergence below is organized in the six phases of convergence describe above. Cognitive activities and their cognitive implication are listed in the table below, and numbered in the text with numbers between brackets (i).

4.1 Cognitive activities in Convergence

Phase 1: Preparation. In the preparation phase a group receives (listens, reads) a specific convergence task (1) and process it for understanding (2). Further, they receive instruction about the tools and methods that will be used for the purpose of convergence (3), observe, study or try it (4) and understand it to infer their personal task (5). Finally, a group needs to make the transition from preparation to the actual convergence activity (6).

Phase 2: Analysis. In this phase contributions are verified and marked if they are to be processed in a next step. Contributions are analyzed for fit to the scope (8) to identify similarity (9), to identify relations (10), to verify clarity (11), to verify fit to the class in which it is classified (12), and to assess its importance with respect to personal stakes (13). Next those contributions that don’t fit the scope (14), are inconsistent relations or classifications (15), are unclear (16), or are similar (17), are marked. Markings can be made with pens, colors, though re-location, or verbally. Visual marks help identification for the purpose of retrieval.

Phase 3: Core Convergence. In the convergence process firstly, contributions can be marked to be included in the converged list (18). Next, similar contributions can be merged (19), or different contributions, can be rephrased to elicit their uniqueness (20). Contributions can be related. For the purpose of simplifications relations (causal, sequential or other) (21) are distinguished from abstract classes (22).

Relations can also be visualized (23). This can be done e.g. by linking contributions, marking the contributions in the same way, locating them together, or coloring them.

Relations, visualizations and mental models can be inconsistent, causing the revision of relations, or re-classification of contributions (24). When summarizing similar or related contributions, a new contribution is created that encompasses the content of these contributions (25). When contributions are unclear, they
can be rephrased to make them clear (26), or the can be explained to the group, to create shared understanding (27). Finally, contributions that don’t fit the scope of the convergence task can be rephrased to ensure the fit (28), or they can be discarded (29). Once contributions are converged, they become clearer, and they form a structure. Participants often have personal stakes in the structure. For instance the structure can reflect one perspective better than another perspective, or the structure can have implications for future tasks or implied quality or relevance of the contributions. Therefore, convergence activities are designed to consider implications. When implications are considered to be negative, they will cause iteration to the convergence steps to for instance identify different relations, different clarifications or classifications.

Phase 4: Reflection. Convergence activities can have implications for personal stakes when contributions are discarded (30), when the label for the abstract class is chosen (31), when a relation is elicited (32), when a contribution is clarified or rephrased (33) or when a contribution is selected to be included in the converged list (34).

Phase 5: Overall reflection. Once the set of converged contributions is taking shape, it can also be evaluated as a whole. This can be based on its size (35) for sufficient complexity reduction, based on its fit to personal stakes and perspectives (36), based on its completeness (37), its consistency (38) and its overall quality (39). Overall quality reflection can also lead to reflection on the generation or brainstorming phase. As the converged list of contributions improves, providing more overview of the content of the set, the next step is to evaluate the quality of the whole set on criteria such as e.g. usefulness, innovativeness or feasibility.

Phase 6: Distraction. Distraction can exist of a loop back to ideation (40) (see below), personal thoughts (e.g. other tasks, personal considerations) (41) and external distractions such as a siren, or a picture on the wall (42).

In general many organized convergence activities are about identifying relations, similarities or inconsistency in a set of contributions. Contributions are pieces of information provided by individual participants such as for instance ideas from a brainstorming session. It is often not possible for a single individual to consider an entire set of contributions at once, as it is larger than the capacity of any one individual's working memory. Therefore an underlying coping strategy is to add new contributions to an existing set of contributions under consideration in the working memory (7) and to discard contributions that are no longer relevant (29) or that are marked for a next step (14,15,16,17,18) and thus can be retrieved when required. This makes it possible for the set for consideration to be maintained within the capacity limits of the working memory. Overall reflection determines which information should be reconsidered and thus put back in working memory.

As discussed above convergence can also create synergy when the result of analysis is of better quality than its components, or when it inspires new contributions, which are now classified under distraction, as there is an entire set of cognitive processes that are then triggered [22]. Synergy and inspiration thus cause a loop back to the divergence phase of collaboration. While this loop is not part of the focus of this study, its importance for further research is acknowledged.

Trust is a determining factor that needs to be considered in convergence processes. For instance, if a group is split up into sub-groups, and each sub-group assigned different parts of a convergence task, sub-groups need to trust each other. Group members have to trust other group members not to discard (29) valuable contributions, or manipulate a set of contributions to focus on a specific perspective (21,22,26,28). If such trust does not exist, all group members have to verify all convergence activities for inclusiveness. This can be time consuming, but critical if the converged list is input for (democratic) decision making. Further, the group can consider reviewing each other’s work jointly doing the reflection (30-34) and overall reflection tasks (35-39), while distributing the analysis and convergence tasks [45, 46].

To further validate the overview of cognitive activities and their (in)effectiveness, we asked four expert facilitators to evaluate the overview of tasks. The facilitators had an average of 7 years of facilitation experience, and worked in academia and industry. Their average age is 40. We asked them to consider a convergence task, and to evaluate based on their experience if the cognitive tasks listed will typically occur in this task. Further we asked them to classify the cognitive activity in one or more categories of effectiveness, and to report any missing tasks. We repeated this exercise twice with a clarification round of differences to reach more consensus among the experts. There were no missing tasks reported, but two tasks were merged as they were similar.

Table 1 lists the numbered cognitive activities distinguished from the 10 Convergence ThinkLets, and our experience with these ThinkLets in practice, and our experience if the cognitive activities listed will typically occur in this task. Further we asked them to classify the cognitive activity in one or more categories of effectiveness, and to report any missing tasks. We repeated this exercise twice with a clarification round of differences to reach more consensus among the experts. There were no missing tasks reported, but two tasks were merged as they were similar.

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The results are not yet conclusive on all aspects. But some first tentative conclusions can be drawn. Firstly, experts by majority agreed that all cognitive tasks occurred in the convergence process described. With regards to effectiveness of the tasks, experts noticed a reinforcing effect in the outcomes; when the set of ideas is reduced, it becomes easier to build shared understanding and to organize, and vice versa. Therefore it was often difficult to distinguish effectiveness for one of the three outcomes. As expected, the experts also noticed that some cognitive activities involve other phases of the problem solving process such as conceiving new ideas (brainstorming phase) and reflecting on implications of ideas (evaluation and decision making phase). We will now discuss the effectiveness as rated by the experts.
For the preparation phase, experts found the activities were mainly procedural. Cognitive load of these tasks can be phased before the convergence task to reduce cognitive load, and therefore a clear task and explicit transition is critical. Some experts indicated that the preparation activities can also foster shared understanding.

Analysis tasks were generally not supporting reduction, except for marking the ideas that are out of scope or similar. Shared understanding and overview were affected by the analysis tasks. Task 7, to hold ideas in memory for comparison, was difficult to classify, as it is instrumental to the other analysis tasks. Task 13, to reflect on implications of ideas, is considered by some as ineffective. Depending on a more rational or a more social process of decision making following the process this can be more or less important.

The convergence phase shows a more distinct consensus of experts on the effectiveness of activities. Tasks that reduce the list are distinguished from tasks that focus on identifying relations for organizing and tasks focused on rephrasing and resolving unclear ideas. Remarkable is that for many activities that support organizing and reduction, shared understanding is also listed by several experts as effect. Task 21, labeling the relation between ideas and task 28, rephrasing out of scope ideas where difficult to attribute to a specific success factor, although experts acknowledged the activities take place.

The reflection of implications of ideas, and implications of the converged set were difficult to attribute. One expert explained that these tasks can motivate the group to improve convergence, and to detect deficiencies, but do not directly contribute to the outcome. Some considered these activities procedural, but others did not see a coordinating effect of these tasks.

Finally, distractions were classified by a majority as ineffective. However, a change of perspective can give insight that leads to more shared understanding or a different way to organize ideas. Further, experts noted that a new idea is not really a distraction, but rather a loop to the brainstorming phase.

5. Reducing cognitive load in convergence

Given the classification of the cognitive load for each of the activities distinguished above, this section explores means to reduce ineffective and extraneous cognitive load in convergence, and to facilitate groups to focus cognitive effort on those cognitive activities that are most important for a specific convergence task.

To this purpose the techniques used in educational design to reduce cognitive load of learning and problem solving tasks were evaluated for their applicability in convergence. Pollock et al [20] suggest that in tasks with high cognitive load information can best be taught in two steps. First the learner is offered a basic framework which can then be used as a basis to learn the complete information with the interaction to the initial framework [20]. This is called the isolated interacting elements approach. Associated is also the pre-training effect; better transfer when the learner recognize the concepts as part of a structure [47]. This effect is recreated when relations are identified to structure and organize the converged set of contributions. While it takes cognitive effort to setup the structure at first, in the later phase of the convergence activity, over time the structure supports the activity making it easier to recognize relations and to create consistency. A side effect is that contributions are grouped or related. This relates to the segmentation effect [47]; better transfer if material is presented in segments, that can be controlled by the learner, then as continuous whole. Thus, classifying contributions in categories should reduce cognitive load of creating an overview and holistic understanding of the set of contributions as a whole. Parsimoniousness of the set of contributions implies that the set of contributions contains all information required to understand the problem and solution, yet no interesting but extraneous information [47]. Redundant information increases cognitive load and has no added value to performance or learning [48, 49]. This is called the Coherence effect [47] or the redundancy effect [47]. Some convergence approaches have higher levels of parsimoniousness of the output than others because of the structure they offer, depending on the criteria they focus on (scope, overlap, clarity, and inconsistency in structure[50]).

To reduce extraneous cognitive load, a first technique is integrating information to reduce split attention. When information is offered in separate components (e.g. picture and separate text) and these components are not self-explanatory, both need to be held in working memory to process the information. Integrating text in a picture will therefore require less cognitive capacity [48], which is named special contiguity effect [47]. This effect is very closely related to the way in which the set of contributions and the converged set are visualized; for instance, when collaborative modeling approaches are used, their visualization can help to reduce split attention. When converged contributions are clearly marked, this can support the process, as marked items can be quickly retrieved, reducing the need to analyze the set again to identify the specific contribution. However, too many different markings can increase the complexity of the total set. Also, markings can help to distinguish those contributions that have been converged, from those that still need to be converged. For verification purposes, and to avoid permanent loss of discarded contributions, it is useful to keep a copy of the original set of contributions. However, the representation of the set to modify should not contain both sets at the same time to avoid split attention. Talking about the convergence process can facilitate the use of both the visual and the audio channel for the task.
Based on these insights we offer five guidelines for the design of convergence tasks:

1. **First create a structure, and then identify relations or classifications.** When an initial structure is created, the convergence task becomes easier. For instance first identify key categories, then cluster contributions, and identify categories for the contributions that remain. In this way the structure can facilitate the convergence activity.

2. **Separate reduction from choice.** When convergence is combined with choice or preference selection, it becomes much more complex. Keeping a contribution on the converged list makes it larger, but discussing inclusion of, or discarding the contribution can take much more time, than the extra effort of considering the extra contribution in the next step.

3. **Phase convergence in a ‘rough’ and ‘more refined’ step.** In the first step contributions are converged intuitively, in the next step they are verified more specifically for fit in the scope, overlap, clarity and consistency. This leaves fewer contributions for the more specific analysis.

4. **Phase clarification after reduction.** Like the rough and refined step, this reduces the amount of contributions that need to be verified and when unclear rephrased or explained, reducing the size of the task.

5. **Consider the need for collaborative convergence.** Convergence takes much effort from the group when done collaboratively, while it is not always required to reach consensus over the converged set of contributions. Groups can successfully make choices and decisions based on a fuzzy set of contributions, especially when there is less conflict and misunderstanding in the group. However, a lack of participation in convergence can be an argument to discard the outcome of a later decision phase. Therefore, participation in convergence can be critical. However, in tasks with less implication or in groups that are more cohesive, rough convergence, individual convergence or no convergence can also function as a basis for decision making.

Besides these design guidelines above, it is important to offer tools (manual or electronic tools) for convergence that enable visualization of relations between contributions, and help the user keeping track of original contributions and converged contributions. Further, tools need to ensure that large contribution sets are structured, paced or split over ‘views’ of smaller sets so the amount of contributions that need to be considered remains limited to keep cognitive load of reading and reflecting low enough to leave capacity for convergence activities.

6. **Discussion and conclusions**

This paper provides an overview of cognitive processes involved in collaborative convergence, and a framework within which the implications of approaches for convergence processes are analyzed. For instance, when focusing on shared understanding, the clarification task is most critical, however, structure and reduction can support this task by reducing it in size and offering a mental framework that can serve as a basis for a shared mental model. This framework can inspire designers of collaboration support systems to create their systems in a way that supports groups to benefit from the gains of collaboration while reducing the need for ineffective or less effective cognitive effort.

Further research is required to further evaluate the framework for completeness and to verify the existence of these cognitive activities in various convergence tasks. An approach for this would be to ask participants in a convergence process to evaluate the framework directly after the task, ensuring better recall of cognitive processes [51]. A similar framework has been devised for the cognitive tasks in brainstorming [22]. Next, additional frameworks need to be devised to understand evaluation, decision making and consensus building. Furthermore, interdependencies between ideation and decision making and convergence tasks need to be further examined. During analysis and re-structuring of shared information synergy can be created; merging ideas gives rise to better ideas, concepts or information elements. While this effect is highly relevant, it seems to be a secondary effect, not directly related to a single cognitive task, but rather to a combination. Finally, three styles or aspects of convergence are presented. They can be combined or phased as activities. It is important to further understand the interplaying effects of these convergence activities on cognitive load.

**References**


