Cognitive Load in Collaboration - Brainstorming

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Abstract

Designing collaboration support is a complex social technical task. One of the key production factors in collaboration is cognitive effort. Understanding the cognitive load involved in collaborative tasks is therefore important to support the design of collaboration support. In this paper we derive a framework of cognitive activities involved in brainstorming, a very common and well-studied collaborative task. The framework is based on an overview of brainstorming techniques, and literature on brainstorming. Based on the framework, several techniques to reduce cognitive load from education literature are revised, and we discuss their implications for the design of brainstorming tools. 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. In knowledge intensive collaborative tasks the main ‘production factor’ is cognitive effort. Furthermore, collaboration requires a team to perform a task jointly, thus requiring interaction and coordination of cognitive effort. Therefore the cognitive load involved in collaborative tasks will be a key determinant of productivity, and is due to the effort spend on interaction, higher than the cognitive load involved in individual tasks. Collaboration is challenging, and often groups and teams use some form of support in their collaborative effort. This support can be facilitation of the collaboration process or technology to support interaction and collaboration. Examples 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 [1]. Cognitive load theory (CLT) offers various design principles to efficiently and effectively use cognitive capacity [1] 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 [2]. To gain an understanding of the effectiveness of interventions in collaborative effort (made though collaboration support) and to resolve the conflicting findings with respect to the effects of collaboration support, we need to study interventions in collaboration in more detail, and with a focus on cognitive effects of these interventions [2, 3].

In order to design interventions that improve cognitive efficiency and reduce the demand on the central executive in collaborative tasks we need to understand cognitive patterns in collaboration. In this paper first steps will be presented 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 we will derive a first understanding of the role and design implications of cognitive load in collaboration.

2. Background

The concept of cognitive load is associated with the assumption that our short-term or working memory, also called central executive is limited to seven plus or minus two information elements [4-6]. Besides working memory the model assumes that we have a long-term memory in which information is stored, in so called schemata [7]. Our working memory has a limited capacity to process information. This capacity can be occupied with productive and unproductive mental activity.
Productive mental effort in brainstorming is for instance spent on generating a new idea, understanding a different perspective, storing new knowledge in your long term memory, and creating higher level schema, that are processed faster or even unconscious [8]. Some mental effort can be instrumental to these processes, such as listening, acknowledging, explaining one’s own perspectives. Finally, people also occupy their mental capacity with things that are distracting them from their current task, e.g. remembering to buy a birthday gift later, a noise in the hallway, etc. Besides off-task load, also on-task load can be ineffective. This is called extraneous load, cognitive load imposed by the way information is represented, rather than by the cognitive complexity of what needs to be learned. In brainstorming this for instance occurs when several people contribute the same idea in different wording. These ideas take time to read, and to understand their similarities and differences, while in the end, they do not add to the shared understanding of potential solutions.

Cognitive load can be defined as the cognitive effort made by a person to understand and perform his task. It has both a task-based dimension (mental load) and a person-based dimension (mental effort)[1]. To understand implications of cognitive effort we need to understand that knowledge we process is stored in our long term memory in schema. Through automation, also called chunking [4, 5], larger schemata can be used in the working memory as a single component. Therefore, the larger the schema, the more information we can process in the same time in our working memory, the faster we can gain new understanding and combine schemata to find solutions or answers to problems.

The cognitive load theory in the context of learning explains how we use our cognitive capacity to construct schemata. There are 3 types of cognitive load [7]:

- Intrinsic cognitive load, is the cognitive load that is inherent to the task, and that is defined by the intrinsic task complexity.
- Extraneous cognitive load, is the cognitive load caused by the presentation and transition method of the information.
- Germane cognitive load, is the cognitive load instrumental to building the schemata and storing them in the long term memory.

Intrinsic cognitive load of a task depends on the experience one has on the topic. When you hear or read something familiar, it takes less cognitive effort to process it, than when it is new to you, and you have difficulty connecting it to schema in your memory. Also, the complexity of the information that needs to be processed will affect the cognitive load of this processing. When a task has a very high cognitive load, higher than the cognitive capacity of the person executing it, it will cause slow and inefficient processing. When the task has very low cognitive load, mental capacity is free for the processing of other information, this can cause people to get distracted. Germane cognitive load is the label used for productive cognitive load. Extraneous cognitive load is the load of unproductive cognitive load. For instance when information is offered scattered, in a non-structured way, it takes additional effort to distil and structure the knowledge in order to process it. The cognitive effort spent on this task is perhaps not necessary, when information is offered more concise, the same knowledge can be processed faster and better.

CLT offers different methods to reduce extraneous cognitive load such as offering parsimonious information elements and avoiding split attention that is caused by disintegrated or unstructured information [1]. As intrinsic cognitive load is inherent to the task complexity, it is less easy to reduce this cognitive load. However, Pollock et al [9] suggest that the intrinsic cognitive load can be reduced for complex information that are difficult to process even with very low extraneous cognitive load. Also research has reported initial results on stimulating learners explicitly to construct and automate schema, increasing productive germane load [8]. CLT is focused on understanding and improving instructional design to improve learning efficiency and effectiveness. In collaboration cognitive load has many more sources. It can origin from the information shared among the participants though various communication channels, from constructing and thinking up new information, from explaining or arguing things, from assessing value, implications and effects of decisions, from various procedures, and from distractions. In the next section we will explore cognitive load in a typical collaborative task; brainstorming.

3. Cognitive load in brainstorming

Brainstorming is originally coined by Osborn, [10] who set a specific set of rules to stimulate ideation productivity. In this paper we will use the term brainstorming a broader meaning encompassing various variations of ideation techniques, with or without technology support such as Electronic Brainstorming Systems. Brainstorming is an approach typically used in problem solving
tasks, which are characterized as imposing high cognitive load [11]. A collaborative task with high cognitive complexity is suitable for a collaborative approach as the transaction costs of coordinating collaboration are limited compared to the advantage of distributing workload of processing the problem [12]. In brainstorming literature a similar result is found when comparing nominal groups with interactive brainstorming groups. Nominal groups let participants brainstorm individually, without sharing their ideas. The results of such groups are compared with people who brainstorm in groups, sharing each idea when it emerges. Findings are conflicting, but many studies found that especially in small groups and for easy tasks, nominal groups are more productive [13]. The solution to this riddle has been the subject of several studies. Santanen [14] suggests that the brainstorming environments and tasks that were compared are not the same, and that the environment and instructions to the group can have a very large impact on the outcome. Henninger et al [2] suggest that the difference is caused by the cognitive effort required for reading the ideas, which is not calculated in the experiments with a nominal brainstorming approach. Other effects discussed are production blocking (waiting for a speaking turn) attention/concentration blocking (holding on to an idea) and attenuation blocking and evaluation apprehension (considering the relevance of the idea) [13, 15] further, the effect of stimuli [16, 17] in a positive sense, or as cognitive interference or spreading [18], when other ideas interrupt, or lead to distracting association are important factors that indicate that cognitive load of the brainstorming task affects productivity. Potter and Balthazard [19] did an more extensive study on these phenomena and listed distraction from reading, cognitive effort of formulating and typing ideas, striving for originality (a cognitive judgment of quality), cognitive effort of trying to understand the ideas of others and cognitive effort of trying to follow someone else’s train of thought instead of one’s own. They also found evidence that these distractions result in lower productivity and quality.

In brainstorming people share ideas they conceive with respect to a problem or question. They share these ideas in the group. The sharing can happen through discussion, writing or typing. When people can brainstorm ideas in parallel, they generally create more ideas as it avoids production blocking [20]. On the other hand explicating an idea vocally, in writing e.g. on a card or typing will also require different amounts of physical and cognitive effort. Next, ideas are shared and displayed. This can require (cognitive) effort as well, for instance when putting stickies on the wall, or when a scribe has to write down the idea on a flipchart. To avoid that people are think too narrow, scripts are used to make it safe to share ideas, either by forbidding critique [10] or by offering anonymity [20]. These studies thus assume that people consider the implications of ideas they share, and that these considerations have a negative effect on quality and productivity. The way in which ideas are captured also has an impact. When a long list is made, it can cause information, and thus cognitive overload, this can be resolved by offering a structure to capture ideas [21], e.g. categories, or a mind map for instance. To stimulate the creativity of ideas various interventions have been described. Productivity can be affected by setting a target [22] and by offering stimuli [16, 17], Some brainstorming methods encourage people to build on each other’s ideas [10], or even to criticize them to stimulate improvement [14]. However, criticizing does shift attention to cognitive processes that are less productive in creating new ideas. Responding or improving an idea will also require a reflection process. Finally all these different aspects of the brainstorming task which cause cognitive load, and of the environment in which people share ideas that can impose additional cognitive load, needs to be understood. For this we need a more detailed overview of the cognitive demand of the brainstorming effort. While the studies above provide empirical evidence for these effects, none of them offer a complete overview of cognitive processes involved in brainstorming. Based on the literature we will attempt to make a first overview of these cognitive processes.

4. Cognitive brainstorming demand

To assess the classification of the instrumentality of the cognitive processes involved in brainstorming, we need to explore what we consider effective cognitive effort in light of brainstorming. Traditionally the assumption is made that the goal of brainstorming is to find many ideas, of high quality. While studies have confirmed a correlation between quantity and quality [19], others see this relationship as more complex [23]. However, in practice there is a range of purposes for idea generation techniques ranging from gathering known solutions or problems, to creatively thinking of new ideas. Furthermore, idea generation is often used as a first step in a larger process that involves idea structuring and organizing, and decision making and consensus building around a final solution [24]. While some elements of ideation techniques might impair creativity, they can be instrumental for creating shared understanding which is useful in these later phases of the process.
Therefore we classified cognitive steps that are instrumental to mutual learning separate from cognitive steps that directly contribute to ‘thinking about new ideas or their quality’. Stimuli effects (being inspired by ideas of others) we therefore categorized as effective for learning, which can cause triggering of new ideas, and is instrumental to later processing of the ideas generated.

We will now create a first overview of the cognitive processes involved in brainstorming. The various cognitive activities and their cognitive implication are listed in the table below, and numbered in the text with numbers between brackets ( ). Some of the cognitive processes directly produce new ideas such as ‘conceiving an idea’ (4). Others, do not directly contribute to productivity but do help the group to lean from the ideas of others and to develop shared understanding. Mutual learning and shared understanding can inspire (but also distract) new ideas, but these processes are especially important in follow-up phases after brainstorming, such as convergence and consensus building. An example of these is ‘understanding the ideas of others’ (9) Besides effective cognitive load, there are processes that are needed for the task, while the cognitive load they impose does not directly contribute to productivity. Examples are ‘cognitive effort required to understand how the tools used work’ (2). Finally some cognitive processes can be triggered in a brainstorming process, which do not contribute to the brainstorming effort at all. An example of this is ‘external distractions’ (19).

We examine the cognitive processes involved in brainstorming in the order in which they first occur, and indicated loops in the process in the table below. In this case we assume that someone (a facilitator) instructs the group to do a brainstorm; that the group members do not have to coordinate their effort themselves. The brainstorm then starts with understanding the problem or question. (1) The problem is communicated to the participants, and they need to understand this and infer their individual task. This process does not contribute directly to the outcome or to learning, and thus can be classified as extraneous. Next a similar process happens to understand how to use the tools offered to capture ideas (2). Finally, before the participants starts brainstorming, a cognitive process will happen that covers the transition from passive to active participation (3).

Now the participant will start conceiving ideas. This can happen in different ways as described above (4). Once an idea is conceived, the participant needs to capture and share the idea. Depending on the tools used for expressing the idea and capturing it, it might be the same process (e.g. in writing, or recording) or a separate process (when brainstorming verbally using a scribe) (5). If the group works in their brainstorm with a structure (e.g. mind map or tree structure) participants need to consider where to place the idea (6). Placing is a productive process, while considering where to place it constitutes learning and shared understanding. Another process, that might happen in parallel with the processes of conceiving and placing ideas is the decision to share ideas (7). This is an individual reflection process in which the participant considers the merits of the idea and its implications. In non-anonymous settings, participants will reflect on the impact of the idea on their personality. In all cases the implications of the ‘idea if executed’ will be –to some extent- considered (e.g. feasibility). Once an idea is shared, participants can think of a new idea (loop to 4), or read the ideas of others (8). When reading, participants reflect on the implications of the idea (10). From this reflection a learning effect takes place, which can be extended when effort is made to understand differences in meaning caused by e.g. differences in background, culture, language or perspective (9). Learning can take a deeper form when the idea is linked to active memory schema (12). Participants will also reflect on the implications of ideas of others (11), and this might lead them to either conceive a new idea, or to respond/react to the idea (13).

In case of a response, a similar process as for sharing an idea emerges. Creating responses can be productive (14) (although they might be less effective in providing solutions directly, they could sharpen solutions), the processes of capturing them will again pose extraneous load (14, 16), and assessing their implications to determine willingness to share will constitute learning (15). During the process participants might also reflect on the extent to which the total set of ideas produced by the group will offer the required solution, and if the set is complete, which in the case of quality reflection can be considered learning, and in other cases extraneous (17). Finally people can be distracted when they work on off topic ideas, conceive them or when other things are on their mind, either with respect of the task and its context or with respect to personal/non task related issues (18, 19).
Depending on the context of the brainstorm, these cognitive processes will take place in a group process. While some interventions might reduce cognitive effort, they depend on trust. For instance, we could offer the group only part of the ideas of others, in a slower pace than they are generated. This would reduce the cognitive effort of reading, but when this is concerning to the participants, if they don’t understand if and why some ideas are not reflected (and thus taken into account for decision making later in the process), they will spend cognitive attention to understanding the process, which will further distract them. Or when working anonymous, reducing the need to reflect on implications of ideas, anonymity should be trusted, other way this can become a distracting concern.

5. Techniques to reduce cognitive load and their use in brainstorming

To find approaches to reduce cognitive load in brainstorming, we first review the techniques used in educational design to reduce cognitive load of the learning task. Pollock et al [9] suggest that in tasks with high cognitive load information can best be taught in two steps. First the learner is offered a basic framework that can be schematized and in which interaction between information elements is mostly removed. This schema can then be used as a
basis to learn the other material by offering the complete information with the interaction to the initial structure [9]. 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 because they learned their key characteristics in a previous step [25]. This effect is recreated in the structured brainstorm. In mind maps or branch building tools for instance, the group works on its ideas in a hierarchical structure. While placing ideas (6) requires cognitive effort, the familiarity effect will help the participants memorize and place the concepts they shared, giving them more overview, and helping them to create a mental map of the solutions shared. A side effect is that ideas are grouped on separate pages. This relates to the segmentation effect [25]; better transfer if material is presented in segments, that can be controlled by the learner, then as continuous whole. Thus, capturing the ideas on separate pages will reduce cognitive load in brainstorming and reduce the amount of reading after each contribution, leading to more focus on ideation itself (4).

In brainstorming a lot of ideas can be off topic, double or partially overlapping. Also the expression of the ideas can be more or less straightforward. Parsimoniousness of implies that the set of ideas contains all information required to understand the problem and solution, yet no interesting but extraneous information [25]. This is also called the Coherence effect [25]. Redundant information increases cognitive load and has no added value to performance or learning [26, 27]. This effect is also called the redundancy effect [25]. Some brainstorming approaches cause higher levels of non-parsimonious output than others because of the structure they offer. e.g. when using a clustering of topics like in a brainstorm in different categories, or in mind maps, it is more likely that participants read that their idea is already shared, and refrain from sharing it again. While this reflection distracts from generating ideas, the resulting list is easier to process in later steps. Organizing ideas while brainstorming will also help the group to make the reflections on performance (17). In a less structured brainstorm this is less likely. Therefore reading ideas of others before sharing, and clustering similar ideas will reduce the complexity of the total set, reducing cognitive load of understanding the brainstorm outcome (9,10,17) for decision making.

There are several techniques and methods to decrease 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 [26]. This effect is named special contiguity effect [25]. A similar additional effect is achieved if cognitive load is spread over the visual and audio channel for instance by combining video with narration instead of video with text. This is called the modality effect [27]. In brainstorming techniques these effects are very closely associated with the tools used to brainstorm ideas. When placing flipcharts on the wall and brainstorming with stickies, split attention can be caused when having different flipcharts at different places in the room. In an electronic meeting environment split attention can be caused by the interface used. For instance when relations between the structure and the ideas are unclear (6), this can cause split attention, and requires additional cognitive effort to understand the structure. The combination of audio and visual processing is difficult. As audio-based brainstorming would distract other participants it seems difficult to implement in a synchronous face to face setting. Perhaps future brainstorming with speech recognition in combination with screen display of the ideas could enable the use of this cognitive efficiency in a distributed setting.

To facilitate brainstorming groups in creating overview, and in temporizing their own cognitive process to avoid distraction from the actions of others, tools have been developed to enable participants to click a button when they would like to read ideas of others for inspiration [28] (8) and to enable visualization of different structures (6) and links between contributions of participants [29]. This framework of cognitive processes involved in collaboration will help us to assess the costs and benefits of such tools in more detail and it might inspire to design others.

Anonymity of the entire process can reduce the consideration of implications (7,15). Depending on the trust in anonymity, and the need for the ‘psychological safety’ anonymity offers, anonymity could cause an ‘overall decision to share ideas’, which would drastically reduce the cognitive load of these steps. On the other hand, when anonymity is not trusted, it could increase the consideration of implications of sharing [20, 30].

Summarizing we can offer five considerations for practitioners when designing a brainstorming task.
1. **Providing psychological safety.** Many cognitive processes are listed that consider reflecting on one’s own ideas or those of others and their implications for decisions in a later phase, or for implications on reputation. Facilitation interventions and tools or technology can be used to provide psychological safety which can cause a ‘one time judgment’ or establishment of trust, that reduces the cognitive attention to these reflection processes. Examples are creating (partial anonymity) but also setting ground rules like Osborn’s no criticizing can help here. The extent to which psychological safety is needed depends on the characteristics of the group and task. A negative effect of psychological safety is abuse like free riding and flaming.

2. **Using a structure.** When offering a structure to brainstorm ideas in, this can help to scope the brainstorm (people will think along the seeds of the structure, not beyond it) which can inspire the brainstorm, but also limits it, making it less useful for ‘out of the box thinking’ brainstorms. Next, it will help the group to gain overview and shared understanding of the set of ideas. Further the structure helps to judge completeness of the brainstorm, and therewith reduces double ideas improving parsimony. On the other hand using a structure poses some additional cognitive load of placing ideas, and will more likely trigger participants to read ideas of others, which improves learning and shared understanding and can inspire, but at the same time distract from creativity. Overall, structures are thus useful except when a goal is to get very wild or out of the box creative ideas. In those cases creativity techniques as listed in (4) and described by Knoll and Horton [17] might be more useful, combined with a non-structured way of capturing ideas. Often, convergence of non-structured idea-sets takes more effort and time than convergence of structured idea-sets.

3. **Seeding.** To stimulate creativity, we can prompt the group with directions or perspectives to the problem [17, 19, 31] Pacing these is important to avoid distraction when other ideas conceived still need to be captured. Also, these techniques are mainly useful in cases where new ideas are required, not when existing solutions or known alternatives are gathered.

4. **Quality constraints.** When brainstorming ideas in groups, shared understanding of the ideas might be important in future steps. Therefore it is possible to set quality constraints to ideas, such as ‘ideas for new products: list the product, its function and target user’. These ‘contribution frameworks’ can increase quality, but cause high cognitive load when eliciting an idea, and therefore reduce creative thinking.

5. **Interaction.** When a group needs to work further with the set of ideas they generate, shared understanding of those ideas can benefit convergence and consensus building processes. While reading ideas can be done completely separate from the brainstorming process, afterwards, (thus not distracting from conceiving ideas) this does not create the same effect as an interactive brainstorm where participants react and respond to each other’s ideas, which supports reflection on ideas, shared understanding, clarification and the creation of shared language. To benefit from both effects, the brainstorm can be phase; first working without interactivity, and later adding the option to reflect and respond to ideas of others as a second phase in the brainstorm. This can help to focus cognitive effort on each of the tasks separately, reducing the cognitive complexity caused by the combination of these processes.

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

6. **Discussion and conclusions**

This paper aims to offer an overview of the possible cognitive processes involved in a common collaborative task; brainstorming. The overview offers a framework to assess the cognitive implications of various types of brainstorming approaches. Typical studies on brainstorming effects compare input variables (group size, task type, tool used, instructions, etc.) and output (number and quality of ideas). We can use this framework to explore in more detail what cognitive implications of
the input variables need to be considered to understand implications on the outcome of brainstorming. For instance, when we are mainly interested in new ideas, focus should be on step (4), and reflection (7, 15), reading (8), responding (11) and placing (6, 14) are less productive. In other cases shared understanding and inspiration are important, as these processes are required to evoke understanding and reflection (9, 10) for the following decision making process.

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 evaluate the framework for completeness. Next, we need to create additional frameworks to understand e.g. convergence, decision making, and collaborative modeling. In these processes the balance between effective and ineffective cognitive tasks is more difficult, as shared understanding, which requires the building and comparison of schema, will be more essential to the task, while at the same time, this can uncover misunderstanding and distracting associations, which are less effective. A third path for further research is the simulation of collaboration processes at this level of detail. Being able to simulate the process will give us a further understanding of interventions that cause ineffective cognitive effort.

References


