GroupMind: Supporting Idea Generation through a Collaborative Mind-mapping Tool

Patrick C. Shih, David H. Nguyen, Sen H. Hirano, David F. Redmiles, Gillian R. Hayes
Department of Informatics
Donald Bren School of Information and Computer Sciences
University of California, Irvine
Irvine, CA 92697-3440, USA
{patshih, dhn, shirano, redmiles, gillianrh}@ics.uci.edu

ABSTRACT
Collaborative brainstorming can be a challenging but important part of creative group problem solving. Mind-mapping has the potential to enhance the brainstorming process but has its own challenges when used in a group. We introduce GroupMind, a collaborative mind-mapping tool that addresses these challenges and opens new opportunities for creative teamwork, including brainstorming. We present a semi-controlled evaluation of GroupMind and its impact on teamwork, problem solving and collaboration for brainstorming activities. GroupMind performs better than using a traditional whiteboard in both interaction group and nominal group settings for the task involving memory recall. The hierarchical mind-map structure also imposes important framing effects on group dynamics and idea organization during the brainstorming process. We also present design ideas to assist in the development of future tools to support creative problem solving in groups.

Categories and Subject Descriptors
H.5.3 [**Information Interfaces and Presentation (e.g., HCI)**]: Group and Organization Interfaces – *collaborative computing, computer-supported cooperative work, evaluation/methodology, synchronous interaction.*

General Terms
Design, Experimentation, Human Factors, Measurement, Performance, Theory

Keywords
Brainstorming, Collocation, Formal and Informal Structures, Group Dynamics, Large Display, Mind-mapping

1. INTRODUCTION
Many creative tasks begin with a phase that includes a single individual working alone or multiple people working collaboratively to generate a large number of ideas. Osborn first coined the term for this process, *brainstorming*, in 1953 [42]. Contrary to decision-making techniques that aim to eliminate or dismiss unsuitable ideas and reach a final consensus, the brainstorming process focuses on gathering as many ideas as possible. In his initial description of this process, Osborn claimed that by reducing the amount of self-criticism and criticism from others during this creative process, a group of individuals can produce better results in terms of both quantity and quality.

In the half-century since brainstorming was first studied, many individuals have considered factors influencing how best to generate a large number of ideas as well as how best to study that process [4, 5, 13, 31, 53]. Hymes and Olson synthesized Diehl and Strobe's review of brainstorming productivity losses and laid out five of the most common hindrances of the group brainstorming process [17, 27]:

- *Evaluation apprehension*: "working in a group makes one's contributions visible to others, and despite the usual brainstorming instructions not to evaluate others' ideas, the members of a group can still be reticent to contribute their ideas."
- *Free riding*: "individual members of a group might not expend the effort since other members of the group are contributing ideas."
- *Limited air time*: "when only one person can speak at a time, there is limited time for each individual to contribute."
- *Production blocking*: "because of limited air time, individuals often have to hold on to their contributions until they get a chance to report them, and as a result they might forget them, or they might decide not to offer them; in either case, the act of holding on to them will prevent them from thinking of other ideas."
- *Cognitive inertia*: "at each moment only one line of ideas is being generated, since they are reported serially; groups will therefore tend to pursue fewer different kinds of ideas."

Despite these hurdles, group brainstorming has continued to be used in both corporate and academic environments. Alternative methods were developed to aid the process of brainstorming. One effective method, the nominal group technique (NGT), allows each member to brainstorm separately, and later presents individual findings sequentially in a group virtually eliminating production blocking and postponing evaluation apprehension [13]. However, NGT can lack the social and collaborative aspects of brainstorming as a group exercise. Such engagement can enable the production of more novel or higher quality ideas during the idea generation process.

In this paper, we present GroupMind, a collaborative mind-mapping system designed to support brainstorming, and a semi-controlled study of its impact on idea generation. GroupMind supports real-time collaboration (distributed or collocated) for developing and editing mind-maps through words and images. This tool can be used for a variety of processes, all of which might include groups working together to solve problems. Our study focuses on GroupMind's effects on teamwork, problem-solving and collaboration, specifically during brainstorming tasks in collocation. Our results indicate that, as traditional literature suggests, GroupMind as an electronic brainstorming system (EBS) performs better than a whiteboard for both group and nominal tasks. Furthermore, GroupMind's hierarchical mind-map structure allowed participants to perform particularly well for the task that primarily involves memory recall and has no significant improvement for the task that requires more abstract conceptualization. We also found that structure and process constraints impose important framing effects on group dynamic and idea organization during the brainstorming process that should be accounted for in future designs of electronic meeting support systems.

2. MOTIVATION AND RELATED WORK

In the past half-century, a variety of studies focused on enhancing the brainstorming process has been carried out. In this review, we describe the studies most related to this work – previous studies that motivated the need for collocated interactive EBS, studies that demonstrated promising effects of structural formalism on idea generation, and the space they leave open, namely that of collaborative, synchronous mind-mapping.

2.1 Nominal Group Technique

The nominal group technique (NGT) is a method in which each member is given time to brainstorm separately and individually without communicating. The individually generated ideas are later pooled together into a merged list [13, 56]. This process essentially eliminates production blocking and evaluation apprehension during the idea generation process; some researchers choose to call this "deferred judgment" because idea selection is postponed until a later stage of the process [24]. Dennis and Valacich reported that in more than 50 studies, including [12, 17, 37, 43], groups employing NGT generate a far greater number of creative ideas than interactive groups [15]. This result led to development of NGT-like processes which include a mixture of group and individual participations through various parts of the creative activity process. However, the nominal group technique can lack the social and collaborative aspects of brainstorming as a group exercise, because it also prevents the participants from actively engaging and building on group ideas. For this reason, despite the obvious performance under the nominal group settings, people continue to brainstorm in groups. Some researchers choose to call this common notion the *Illusion of Group Productivity* [45, 55].

Subsequently, researchers have considered how collaborative technologies such as electronic brainstorming and meeting systems might impact these ideation processes [2, 15, 22, 23, 39]. These EBS often incorporate benefits of NGT by supporting anonymous input, which eliminates both evaluation apprehension and production blocking. Users of EBS first enter ideas anonymously into a central repository in parallel. The ideas stored in the central repository are selected at random and presented sequentially to the participants in order to trigger new ideas at a later time. Hymes and Olson compared parallel input via a simple shared text editor into a shared workspace to the aforementioned EBS [27, 41]. They found that parallel input was more effective at reducing the effects of production blocking than the sequential turn-taking condition enforced in most prior EBS. Studies of these EBS typically use conventional face-to-face brainstorming using whiteboard as the baseline of comparison to demonstrate performance improvements. Although EBS in general are capable of generating more ideas, in practice, brainstorming with these systems take longer and the participants are less satisfied than those in traditional meetings, and group brainstorming has continued to be used in both corporate and academic environments [26, 33].

2.2 Group Brainstorming

Aside from idea quantity, earlier studies focusing on adapting NGT failed to account for other benefits of group activities that consistently drove people to carry out and to prefer brainstorming in collocated groups. In more recent studies, researchers uncovered important social benefits that led to these preferences. Active social interaction, negotiation, and social comparison, the act of being exposed to a high number of ideas and to common ideas, enhanced the generation of additional ideas [19, 34, 44, 49]. In 2006, Rietzschel *et al* questioned the notion of evaluating idea quality outside of a group decision-making process without considering different criteria, incentive, and task domain factors [48]. Their results indicate that without actively engaging in group discussions, although the nominal groups are capable of generating more original ideas, the ideas were less feasible than those generated by interactive groups. More importantly, the final decisions made from ideas generated in both nominal and interactive groups were of equal quality. Therefore, providing a communication channel to negotiate criteria and incentives in evaluating idea quality as a group in the idea generation process could benefit the group decision-making process as a whole.

Focus on sheer quantitative performance led to the common belief that NGT is the superior method in the community. Specifically, the majority of past work compared brainstorming conditions involving both interactive and nominal groups using either EBS or traditional tools (*e.g.*, whiteboards and flip charts) in the following conditions: collocation with specialized process constraints (*e.g.,* participant anonymity or turn-taking input), collocation without verbal communications (*e.g.*, [62]), remote locations with computer-mediated communications, and remote locations in nominal condition. Barki and Pinsonneault provided a review of EBS in these varying settings [3]. Yet, few studies have been conducted on groups using EBS with the goal of complementing natural group interaction in collocation, a much more realistic scenario. Many general-purpose electronic systems supporting group meetings in collocation (*e.g.*, [52, 54]) have been found to be conducive to group activities in the past.

Subsequently, research has suggested that exploring EBS in collocation or with rich media communication under interactive condition would be a promising path because electronic media have a different balance of process constraints than traditional media [16]. It has also been demonstrated that there are benefits of face-to-face communication such as the inclusion of social nuances, contextual cues, presence, and back communication, which are conducive to creative works that distance work cannot easily replicate [28, 30, 57]. With these prior findings in mind, our study elected to compare groups using either traditional whiteboards or an EBS supporting hierarchical structure in both collocated face-to-face interaction and nominal conditions.

In a similar fashion, adhering to the goal of reducing social influences by minimizing group interactions, previous EBS have often attempted to reduce evaluation apprehension by maintaining contributor anonymity during brainstorming sessions. Although enforcing participant anonymity has been thought of as an effective way of generating more creative ideas and critical comments, studies found that there is no significant difference in both quantity and quality of the ideas generated among groups with similar group size and process constraints [11, 45, 51, 60]. Furthermore, DiMicco *et al* pointed to the fact that anonymity is rarely a feature of today's business communication tools and it is unrealistic to assume real-world groups will interact anonymously to make critical decisions [18]. For this purpose, researchers have been focusing on inducing group participation in collocated meetings by displaying members' participation rates on large display as well as other sociometric feedbacks on smaller personal form factors [18, 29]. Since our study focuses on analyzing interactive groups in collocation, we opted to color-code the ideas generated by participants in the shared workspace in order to facilitate group discussions. The effect of this feature is studied and analyzed as well.

2.3 Structure and Formalism

gIBIS is an early electronic meeting system that supports using formal structure to support group-decision making process [9]. It exhibits a concept-map-like formal method, meaning that its workspace is composed of a network of nodes and links. The nodes have specialized and color-coded functions such as Issues, Arguments, and Positions, and links represent specific actions such as Responds-to, Supports, Objects-to, Questions, and Replaces, rather than a general association. The goal is for members to vote and resolve issues in turn-taking fashion, rather than to support idea generation. Shipman and Marshall published an influential study in 1999 detailing how formal structures, even if carefully designed for the user and the task domain, could hinder creative thinking [50]. Formal structures inevitably introduce higher cognitive overhead in learning the system formalism, disrupting tacit knowledge, enforcing premature structure, and discourage creating situational structure to fit appropriate context. In order to successfully design structures into system interfaces, the structures representing object relationships must match the level of formal expression entailed with the goals and situations of the users and inherent in the information. Incremental formalization techniques were suggested as one way of reducing cognitive overhead and allowing natural structure to emerge as group activity progresses.

Prante and *et al* were the first to take account of Shipman's suggestions and studied the effects of structuring the idea space during the idea generation process [46]. In their study, they compared a mind-mapping tool exhibiting a turn-taking work mode via application sharing, where only one subject at a time can alter the shared idea space while each subject can perceive the changes immediately, to two other electronic whiteboard systems, with one also employing the turn-taking work mode and the other electing parallel input. A mind-map is a tree-like diagram used to represent related ideas and themes using interconnected nodes. The use of mind-maps as an effective method for brainstorming evolved from generating ideas by associations using semantic networks [8]. Their study concluded that the act of collectively structuring shared idea space using a hierarchical structure that is implicit in a mind-map has the potential of improving brainstorming performance over a free-form structure that is assumed in a whiteboard. They also advocated against imposing formal process constraints such as turn-taking input or processed-based brainstorming strategy realized in most EBS based on their experimental observations, a result that is consistent with [48]. They left to future work to study the effect of a synchronous mind-mapping tool on brainstorming as no such tool existed at the time of the study. Our study builds on top of the existing studies by analyzing the usage of a mind-mapping system supporting parallel input in collocation and its impact on idea generation and group dynamics.

2.4 Relevant Collaborative Brainstorming Systems

Commercially available on-line mind-mapping technologies include tools such as Mindjet Connect [35], MindMeister [36], Thinkature [59], and bubbl.us [7]. These web-based mind-mapping tools are designed to allow users to collaborate remotely in distributed teams, and they exhibit near-synchronous connectivity in which users experience a 3-5 second delay. In earlier studies, researchers found real-time and synchronous connectivity to be an essential element for successful collaboration [30, 46]. "The Distiller" developed by The Automatic allows participants to add textual ideas anonymously using keyboards or cell phones onto a wall-size display to reduce evaluation apprehension [58]. TeamSTORM, a freehand creativity tool, allows users to draw images and "doodles" on their personal Tablet PCs and share the desirable ones by uploading them to the public space on a large display in a collocated environment [25]. In building GroupMind, we combined features of these systems by using mind-map to assist structuring the idea space, utilized a large touch-screen display to project shared-workspace information, allowing textual, pen-based, and image inputs via Tablet PCs, and acknowledging individual contributions with name and color identifications.

3. THE GROUPMIND SYSTEM

GroupMind is a real-time collaborative mind-mapping application built on FreeMind, an open source, single-user mind-mapping application [21]. We borrowed heavily in our consideration of design requirements from previous studies and so emphasized in our extension into GroupMind the following features: real-time and parallel interaction, structuring the idea space, no process constraints, and adding an augmented view of shared workspace on public large display [25, 27, 46, 58]. Besides adding

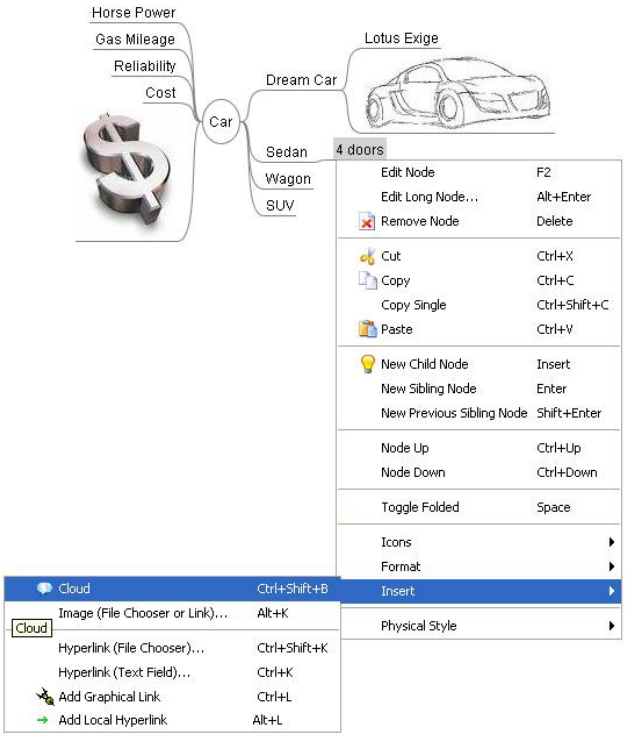

Figure 1. A snapshot of the GroupMind workspace.

functionality for collaboration, the GroupMind prototype also includes interface changes from FreeMind for usability purposes. For example, several extraneous icons for rarely used functionality were removed from the design of GroupMind.

After joining an active GroupMind session, the participant is immediately presented with and is able to contribute to the group's shared mind-map workspace. A list of all group participants can be seen using a drop-down menu. Each line of the drop-down menu displays the participant's name and network location. Each participant is assigned a unique color for easy identification and personalization. Participants can do actions such as insert, edit, delete, copy or group nodes, as well as more complex actions such as distributing files or images. Participants can use familiar desktop interactions (*e.g.*, "drag and drop") throughout GroupMind. They can drag images or sketches from a file or from a web page onto the shared mind-map (see Figure 1). This image is then seen by the entire group.

Users of GroupMind contribute to the shared mind-map space simultaneously with the goal of fostering the group's creative performance. A major challenge in these types of collaborative systems has historically been managing the "undo" functionality [1]. GroupMind supports reversal of actions through a local history, similar to that demonstrated in [47]. GroupMind does not impose any process constraints, such as those found in formal brainstorming methods, and thus encourages natural interactions. It does, however, impose some structure in terms of the end result of a structural diagram of ideas.

In addition to the multi-user mind-mapping application, GroupMind was designed for the explicit use on Tablet PCs supporting both pen-based and text input in conjunction with a shared, large-screen, high-resolution display. Group members have the ability to control the large display by setting its focus on a specific mind-map node using their Tablet PCs for discussion purposes. For example, by controlling what the large, shared screen is displaying, a group member can ensure that all parties are looking at the same area of a large concept map as they discuss a topic. While GroupMind was designed with a shared, large screen in mind, the software itself does not require a large screen. Two users can easily share and collaborate on a mind-map simply by connecting GroupMind using a network.

4. METHODS

To evaluate the impact of GroupMind, we conducted a semi-controlled experiment in which 16 groups of four participants as well as 16 individual participants (80 participants total, 26 females) brainstormed about specific set topics. In the latter case, these individuals were formed into nominal groups of four for the purposes of evaluating and comparing the impact of GroupMind on the nominal group technique. This design is standard across previous brainstorming literatures and is adopted in our study so we could more easily compare our results.

For interaction groups, the experiment was completed in a mid-sized conference room set up specifically for the study. Equipment included a square table capable of seating 8 people at the center of the room. Four chairs were placed around the table, two each on opposing sides of the table. On one of the remaining sides of the table, a large display is placed on one end, with two classroom-sized whiteboards placed at the other end. The two large whiteboards were provided to offset the theoretically unlimited workspace available in electronic systems. In practice, none of the groups exhausted the available whiteboard space, so we believe that the effects of space limitation were kept to the minimum. In addition, since the whiteboards span over two walls of a mid-sized conference room, physical limitation was also removed so that participants could easily contribute in parallel when the group decides to do so.

The large display is a 42-inch touch-screen attached to a rolling mount with adjustable height. In the GroupMind sessions, each participant was provided with a Tablet PC with a 12-inch display. The GroupMind applications on these computers were connected to one another over a wireless network connection, allowing participants to shift seats if they chose. In practice, no one moved a Tablet PC more than a few inches in any direction, from their original placement on the table. During whiteboard sessions, two black markers and four markers of different colors were randomly and evenly distributed in the marker trays of either whiteboard.

For nominal groups, the participants did not have the benefit of the large display when using GroupMind. Rather, they completed their tasks entirely using one Tablet PC. Likewise, rather than using two large whiteboard surfaces, these participant each had access to a single slightly smaller whiteboard and only two markers rather than the six provided to the group sessions. The results of each of the four members of each group were then merged to create the combined list of non-redundant ideas that would be generated were these four an interaction group.

During the brainstorming sessions, participants were asked to brainstorm for fifteen minutes each about two different topics. In one case, the outcomes of the brainstorming activities were to be recorded on a traditional whiteboard, and in the other, to be recorded using GroupMind. The fifteen-minute time limit was selected to offset the difference of input speed between media. In our pilot study, participants exhausted the problem spaces within approximately 12 – 13 minutes. In practice, all group discussions finished well before the allocated fifteen-minute time slot, so we believe that the effects of difference of input speed between media were kept to the minimum.

Using a counter-balanced, randomly assigned, within subjects, 2-by-2 factorial design, each group or individual was assigned to a condition dependant on technology and brainstorming task (see Table 1). Both topics were taken from the literature and designed to reduce bias and prior experience as much as possible.

One of the topics focused on asking participants about life with an extra thumb on each hand (Thumb task) [5]:

> "*We do not think this is likely to happen, but imagine for a moment what would happen if everyone after 2008 had an extra thumb on each hand. This extra thumb will be built just as the present one, but located on the other side of the hand. It faces inward, so that it can press against the finger just as the regular thumb does now. Here is the question: What practical benefits or difficulties will arise when people start having this extra thumb?*"

The other topic focused on explaining the modern world to a Siberian Eskimo (Siberian task) [27]:

> "*Imagine you are going to be visited by a person from a low technology environment, say a Siberian Eskimo who has lived as a hunter gatherer all their life. Generate the longest list of as many things around a modern, middle class house that this person would likely find bewildering.*"

Table 1. Experimental conditions

1st Session	2nd Session
Whiteboard & Thumb	GroupMind & Siberian
GroupMind & Thumb	Whiteboard & Siberian
Whiteboard & Siberian	GroupMind & Thumb
GroupMind & Siberian	Whiteboard & Thumb

Directly before the GroupMind condition, all participants were given a tutorial on GroupMind and allowed to play with the interface until they felt comfortable. Participants were given five minutes as a break between topics. When giving instructions to these topics, we were careful about not suggesting any preferential treatments in ways which groups can interact. When queried by the participants about how they should approach the brainstorming process, we gave explicit instructions during the experiment to contribute simultaneously or in sequence as participants preferred.

Following the brainstorming activities, each participant in the group sessions then completed a questionnaire and participated in a focus group discussion surrounding GroupMind. The questionnaire queried participant perceptions of "leaders" and other group dynamics during each task as well as reactions to the system itself. The group interview then queried the users' impressions, recommendations, and feedback about the system, nuances in coordinating idea generations among the users, and how they chose to participate and contribute their ideas and how they perceive others in group activities.

All of the brainstorming sessions were video-taped and analyzed for effects on group dynamics, leadership, and other human behaviors during brainstorming. The focus group interviews were also video-taped, transcribed, and analyzed for themes related to the effects observed.

5. RESULTS

One of the most measured performance indicator when evaluating any brainstorming process or technology is the quantity of unique ideas generated. Specifically, it has been reported in numerous studies that all other relevant metrics correlate highly with total quantity [4, 14, 17, 23; 61]. Moreover, Briggs' study in 1997 established a causal connection between idea quantity and quality [6]. For the purpose of this study, we measure idea quantity as our performance comparison so we could compare our results to those published in previous studies, though we also focus on observing the effects of social and structural constraints. These results include the impacts of collaborative mind-mapping on layout of ideas, group dynamics, and how participants coordinate concepts using the color identification feature and the large display.

5.1 Impact on Idea Generation

On average, the nominal groups generated more ideas than the interaction groups (**$t(10.66) = 2.10$, $p < 0.03$**), a result that is consistent with previous literatures [41]. When compared across different technologies, users with GroupMind in both interactive and nominal groups generated more ideas than whiteboard (**$t(33.48) = 1.70$, $p < 0.05$**). The overall performance gains can be attributed to parallel input as previous literatures have shown [27].

The two hypothetical tasks are shown to impose different difficulty levels to our sample of the participants. Overall, participants generated significantly more ideas during the Siberian task using either technology in both interactive and nominal groups, which involves memory recall, than the Thumb task, which focuses on conceptualizing a hypothetical scenario (**$t(22.71) = 5.99$, $p = 0.0000$**). According to theories in developmental psychology, abstraction involves higher order of complexity than concretization of objects or events, and could explain the parity in task difficulties [10]. Our balanced experimental design addresses concerns about the difference in the tasks. We used Welch's t-test in our analysis to account for the unequal variances across conditions.

Our results also show a slight indication that groups may perform better on the second topic than the first one ($t(37.29) = 1.05$, $p < 0.15$). This result is not surprising in that one might consider that participants "warm up" to one another and to the brainstorming process over time and with practice [63]. Our counter-balanced randomly assigned experimental design minimizes the impacts of this ordering effect on our results.

In order to demonstrate the effects of allowing hierarchical structure of a shared idea space more fully, we present the results between tasks separately in the remainder of this section. For interaction groups, participants generated significantly more ideas using GroupMind than whiteboard on the Siberian task (**$t(9.83) = 1.98$, $p < 0.04$**). Trends indicate that GroupMind also performs better than the whiteboard for the Thumb task ($t(13.19) = 1.76$, $p < 0.06$). A power analysis indicates that the trend is towards significance for the thumb task and recruiting 8 more groups (2 sets of the 2x2 conditions) would likely change this result.

For nominal groups, participants also generated significantly more ideas using GroupMind than whiteboard on the Siberian task (**t(1.37) = 5.82, p < 0.04**) but equivalent quantities on the thumb task (t(3.81) = 0.26, p < 0.41). Table 2 shows the number of ideas generated from our 2-by-2 factorial design. A chart is presented for clarity and readability as well (see Figure 2).

Table 2. Number of Unique Ideas Generated

Overall	**Mean**	**Std. Dev.**	**t-test**
Interaction Group	63.50	38.67	t(10.66) = 2.10 **p < 0.03**
Nominal Group	100.50	45.53	
Whiteboard	59.89	33.17	t(33.48) = 1.70 **p < 0.05**
GroupMind	82.68	48.18	
Thumb	41.74	14.05	t(22.71) = 5.99 **p = 0.0000**
Siberian	100.84	40.68	
1st Session	64.05	45.10	t(37.29) = 1.05 p < 0.15
2nd Session	78.53	39.38	
Interaction Group	**Mean**	**Std. Dev.**	**t-test**
Thumb & Whiteboard	32.63	13.04	t(13.19) = 1.76 p < 0.06
Thumb & GroupMind	42.29	7.95	
Siberian & Whiteboard	71.57	17.17	t(9.83) = 1.98 **p < 0.04**
Siberian & GroupMind	105.88	45.39	
Nominal Group	**Mean**	**Std. Dev.**	**t-test**
Thumb & Whiteboard	58.00	8.49	t(3.81) = 0.26 p < 0.41
Thumb & GroupMind	60.00	7.07	
Siberian & Whiteboard	130.00	5.66	t(1.37) = 5.82 **p < 0.04**
Siberian & GroupMind	154.00	1.41	

Although GroupMind users generated more ideas than whiteboard users overall, the performance improvements vary across different tasks and group conditions. In this work, groups using GroupMind performed particularly well on the task involving memory recalls but not on the task involving conceptualizing a hypothetical scenario, though the improvement is more apparent for interaction groups than the nominal groups. It is worth noting that all group discussions and individual contributions in nominal group condition finished well before fifteen minutes. Thus, we believe that input speed had little effect on the performance improvements. In other words, performance improvements in using GroupMind were not a result of the speed difference between writing and typing. Therefore, we could attribute the difference in performance improvement using GroupMind across the different tasks to the imposed hierarchical mind-map structure.

Upon closer examination of previous studies focused on mind-map and concept-map, mind-map has been shown to be particularly helpful in associating related concepts [32]. Specifically, research has demonstrated that using mind-map as a studying strategy significantly improves students' memory recall abilities and test

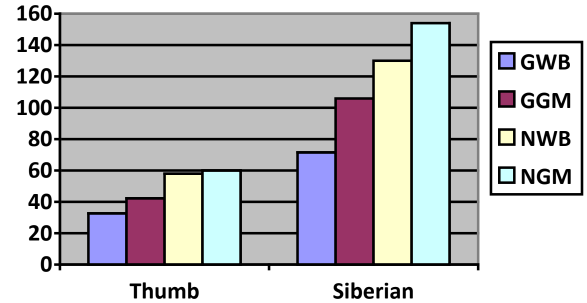

Figure 2: Ideas generated for each brainstorming condition. (GWB = Interaction group using whiteboard; GGM = Interaction group using GroupMind; NWB = Nominal group using whiteboard; NGM = Nominal group using GroupMind)

scores on standardized exams [20, 40]. Since the Siberian task primarily involves the ability to concretize and recall familiar household objects from memory, the mind-map structure adopted by GroupMind as the default method to structure participant's shared workspace significantly benefited their performance on the task. As for the Thumb task, participants' results suggest a high potential for mind-maps to be also useful when used in interaction groups. For nominal groups, the number of unique ideas generated has topped off at the same level indifferent of the technology used. This indicates that the hierarchical mind-map structure did not hinder the individual participants' ability to brainstorm, and the individual participants using GroupMind performed as well as they normally would with traditional whiteboard. Although this could be a result of the freehand drawing capability implemented in GroupMind, an examination into participants' workspaces showed that it is not a primary factor as participants who brainstormed individually in nominal group condition often did not leverage that feature. In short, while mind-map appears to be especially useful for the Siberian task, a task that requires memory recall ability, participants were at least able to perform at equal levels when comparing to the use of tradition whiteboard for the Thumb task, a task that requires abstract conceptualization.

5.2 Layout of Ideas and Formalism

In this work, we found that the enforced spatial structure acted as an implicit facilitator that helped divide each participant's personal workspace in the interaction group, just as Prante *et al* claimed [46]. Participants had an easier time coordinating on categories to work on initially, and the ability to dynamically regroup ideas under different or multiple categories were found to be particularly helpful in comparison to the whiteboard groups. However, there were also some unexpected results. Our results indicate that having been exposed to a formal method of idea organization also influences the perceptions of users related to idea generation. Participants who used GroupMind first often used quasi- mind-mapping techniques when brainstorming with a whiteboard (see Figure 3 and Figure 4).

This finding corresponds to previous studies that formalism could shape people's thinking [50]. However, what is perhaps less apparent is that informal methods can also influence behavior. Just as the mind map structure may influence users to break a topic into categories before branching out into ideas, participants who used whiteboard to brainstorm during the first session often used a list structure during the second task, with GroupMind (see Figure 5 and Figure 6).

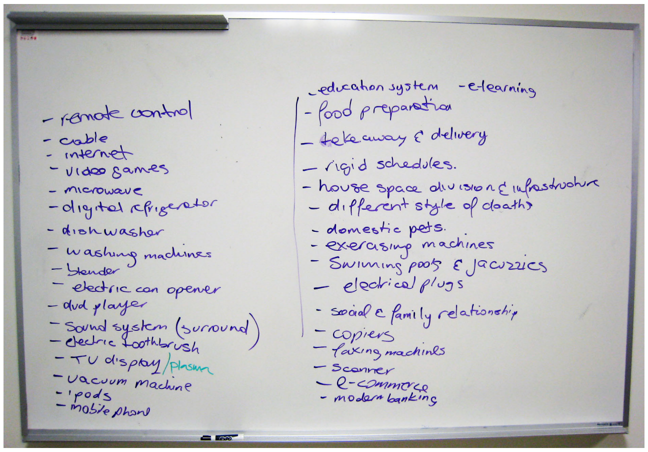

Figure 3: Whiteboard session results before GroupMind.

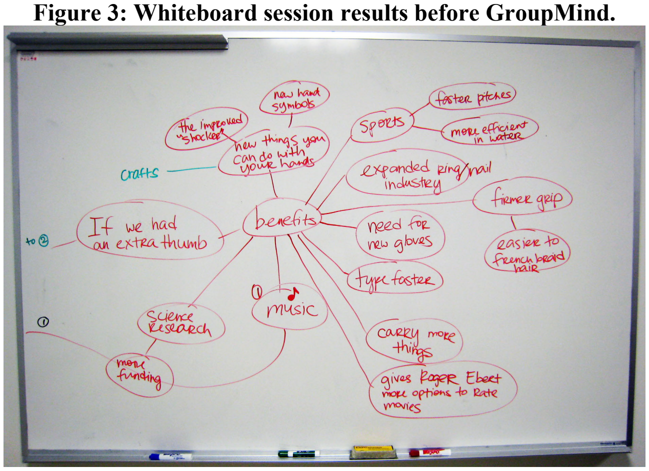

Figure 4: Whiteboard session results after GroupMind.

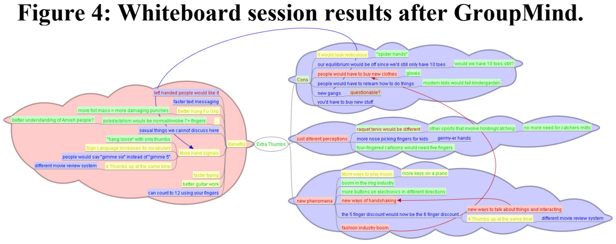

Figure 5: GroupMind session results before whiteboard.

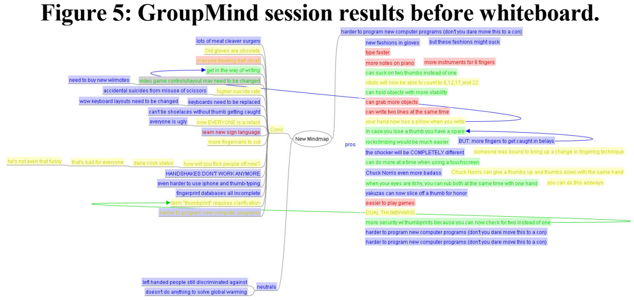

Figure 6: GroupMind session results after whiteboard.

Thus, being predisposed to informal, freehand methods such as available through a whiteboard interface can impact how users perceive and operate an explicitly rigid formal method like mind-mapping. This result echoes Shipman's argument that user situation and goals must be considered carefully when designing for creativity activity, and a successful platform that aims to support such activity must be able to accommodate both formal and informal methods [50].

5.3 Group Dynamics and Leadership

A stark contrast was observed in the groups who used the whiteboard first as opposed to those who used GroupMind first. When using whiteboard first, a facilitator, leader, or a "scribe" in 6 of 8 groups walked to the whiteboard and began recording the ideas verbally supplied by the group. In the case of GroupMind, however, the parallel interactions allowed users to contribute ideas to the shared workspace without having to go through a gatekeeper or facilitator. Interestingly, in those whiteboard sessions that followed an initial GroupMind session, all of the participants continued to participate, each walking to the whiteboard and using a different marker.

In the post-task questionnaire, no leader was indicated by the participants in 6 of 16 GroupMind sessions. In the remaining 10 GroupMind sessions, no consensus was reached regarding a leader. In other words, no distinct leader(s) emerged in the GroupMind sessions. On the other hand, participants in 12 of 16 whiteboard sessions observed the emergence of leader(s). In the remaining four whiteboard sessions in which no leader(s) emerged, three of these groups had used GroupMind first. This result indicates the use of GroupMind can create more egalitarian participation.

Interestingly, in one GroupMind session that came after a whiteboard session, the leader that had emerged during that first session continued to "scribe" for the group using the digital tools as he had with the analog. It was not until a few minutes into the session that another participant in the group began contributing in parallel. This situation confirms the intuition that willingness and ability to participate in a group can be influenced by rapidly established group norms. In this case, those norms were established in less than fifteen minutes. It is also important to note that those norms were also eventually overcome through use of GroupMind.

5.4 Concept Coordination

The freedom to contribute ideas in parallel and without restriction through GroupMind sometimes resulted in new challenges to coordination of those ideas. In group brainstorming sessions, verbal and physical communication can help users keep a common thread of discussion. Using GroupMind, individuals sometimes ignored these cues, choosing instead to remain focused on their own sections of the mind-map. In contrast, during the whiteboard sessions, only one surface – the whiteboard – could be the focus of attention and input enabling simpler coordination. Although coordinating concepts can be challenging through GroupMind, this ability of individual users to work independently models nominal group technique and may contribute to the performance improvement in quantity of idea generation using GroupMind.

The feature of color-coding each participant with a unique color was added with the intention of assisting concept coordination: users could easily distinguish ideas from different authors with a quick glance. However, matching different colors to different users not only allowed people to identify the original author of a generated idea, but also enabled real-time indicators of participation. In some cases, when group members detected uneven distribution of ideas, or free riding, they waited for those people to "catch up" or queried them verbally for their opinions. In other cases, group members openly competed with one another to generate the most ideas in the shortest period of time. Despite the advantages afforded by visual color-coding, however, other cues should likely be used in addition to color to support colorblind users. One such individual, a participant in this study, noted that the colors were of no help to him, because he could not differentiate them.

In GroupMind sessions, a large touch-screen display showcasing participants' shared workspace was also provided to ease the coordination process. The majority of participants reported that they used the large display to confirm the "public" view and ensure it matched their own views of the shared workspace. When the mind-map grew larger than the viewable screen size at their individual stations, they would also use the large screen to orient themselves within the overall picture of the workspace while continuing to work on their sub-region of the map. However, some participants also reported that they have less incentive to look at the large display when the map gets extremely large. Because the resolution of the large display is only slightly higher than that of the Tablet PCs used, the large display only included a viewable area of the workspace slightly larger than what the users could already see on their own screens. This result indicates that a larger display with higher resolution would be helpful to users' personal screens.

5.5 User Satisfaction

At the end of both brainstorming sessions, we asked the participants to fill out a questionnaire on their impressions and experiences about GroupMind on a 7-point Likert scale (see Figure 7). Unlike previous EBS in which users generally reported dissatisfaction in comparison to traditional whiteboard tools, participants in our study generally praised GroupMind for its technological innovation and ease-of-use. Many have also asked whether a "public beta" version would be released so they could continue to use the technology for their group projects and personal purposes. Interestingly, when queried about their use of the tools, despite the significant improvement in contribution and overall productivity of ideas, users reported feeling less engaged. They also nearly universally reported wanting more personal interactions with other group members during the GroupMind sessions. They commented that although they did not *feel* engaged with others, they noticed that others were in fact engaged, because nodes continued to appear and change in their peripheral vision. Nohria had previously reported similar social disengagement issues in the adoption of CMC systems in organizations [38]. Ironically, increasing social engagement and interactions by having groups brainstorming under the interactive settings was one of our original intentions, as it has been found that participants prefer more group interactions. We suspect the social disengagement felt during our study is a direct byproduct of the

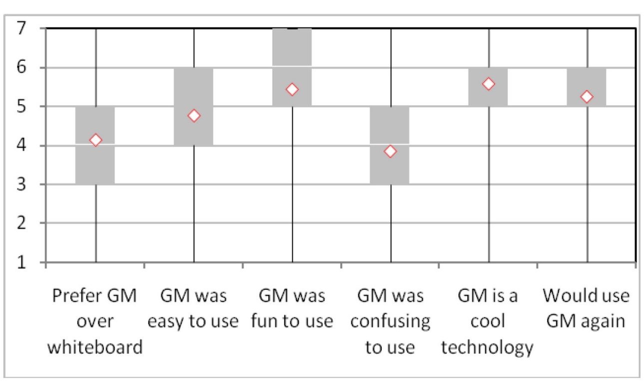

Figure 7. User attitudes toward GroupMind.
(1 = strongly disagree and 7 = strongly agree)

current networked computing and communications paradigm. More studies are needed to determine how to overcome these mediation effects in collocated collaborative works.

6. CONCLUSIONS AND FUTURE WORK

In this paper, we present GroupMind, a real-time collaborative mind-mapping tool that applies proven techniques from creative activity studies. We also present a semi-controlled study that demonstrates the impact of GroupMind on idea generation during group and nominal brainstorming sessions. Although the results of this study demonstrate GroupMind's performance in a semi-controlled setting, there are limitations to our research. We studied a limited number of *zero-history* groups that had no prior experiences of engagements and had no significant stake in the outcome of their results. To truly understand its potential impact on a wide variety of issues, a deployment of the system and naturalistic evaluation of its impact must be conducted. We are currently working toward completing such an evaluation and plan to understand how these results complement those of this controlled in laboratory evaluation. We are also planning on conducting extensive video and transcript analysis on data that could hopefully identify idea *centrality* and their pattern of *associations* on different mediums, and also uncover more clearly the factors influencing group behaviors such as emergence of leaders and member motivations during the brainstorming sessions.

Our findings indicate that a system such as GroupMind can impact other aspects of collaborative, creative problem solving beyond idea generation and brainstorming. GroupMind's hierarchical mind-mapping structure allowed participants to perform particularly well for the task that primarily involves memory recall and has potential of improving the task that requires more abstract conceptualization. Furthermore, structure and process constraints impose important framing effects on group dynamic and idea organization during the brainstorming process. Our results indicate that having been exposed to a formal method of idea organization also influences the perceptions of users related to idea generation. Even less intuitively, being predisposed to informal, freehand methods such as available through a whiteboard interface can impact how users perceive and operate an explicitly rigid formal method like mind-mapping as well. Structural formalism governing interface and idea representations should be accounted for in future designs of electronic meeting support systems. Other findings also suggest that contributor identification, when done successfully, could encourage member participations as well. However, forms of identification other than visual coding need to be explored to accommodate for individual preferences.

User impressions about GroupMind provide empirical evidence that, when interacting with other group members, usage of EBS can be an extremely satisfying experience. However, our study also suggests that usage of electronic systems could introduce social gaps among group members, even when collocated in the same room. Meeting participants do not assume social engagement merely because of the close proximity. While distant users are known to develop a sense of tolerance for lack of social awareness in CSCW systems and are capable of improvising workarounds, the same is not true for physically collocated users. When collocated users feel dissatisfied with an electronic system, whiteboard can easily act as their natural alternative. Therefore, the sense of social engagement must be carefully treated in the design of electronic groupware, especially for collocated usage. New methods that could increase group engagement must be explored for successful long-term usage and adoption of future systems of this kind.

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