Groupgarden: Supporting Brainstorming through a Metaphorical Group Mirror on Table or Wall

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ABSTRACT

To ensure the productivity of brainstorming, group members have to observe several rules. Nevertheless, problems such as free riding or imbalanced participation can occur. We present *Groupgarden*, a metaphorical group mirror providing feedback about individual as well as group performance. We conducted two user studies. We could validate the effectivity of *Groupgarden* in a preliminary study that compared brainstorming sessions supported by *Groupgarden* with sessions without additional support. Results show that the group mirror effectively supports the compliance to particular brainstorming rules and participation is more balanced compared to the baseline. In a second study, we examined the influence of the location of the feedback, wall vs. table, on group behavior. Our results indicate that the location does not influence efficiency of brainstorming, while each location has different benefits. Feedback on a wall seems less disturbing and puts less pressure on the group while a group mirror on a table facilitates communication and collaboration.

Author Keywords

Brainstorming; group mirror; feedback; metaphor; display environment

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Collaborative creativity techniques come with a number of rules: e.g. when using Osborn's brainstorming technique [31] users need to act on rules such as 'do not judge ideas' in order to not harm the flow of creativity of group members. Despite the agreement on those rules, however, social factors and users' focus on the task can lead to undesired behavior and *loss of productivity* [14]: forgetting or suppressing ideas while others are talking (*production blocking*) can lead to less ideas, as well as relying on the efforts of others (*free riding*) or

Figure 1. *Groupgarden* **provides feedback during a brainstorming session.**

fearing judgment of others (*evaluation apprehension*). However, equal participation has shown to be important in brainstorming as it improves quantity and quality of ideas [32].

The problem of unequal participation has been addressed in the literature by group mirrors (e.g. [2, 16]). Group mirrors are systems that provide feedback to a group about specific aspects of their collaboration [24], for example about speaking times or speaking turns. Studies showed that feedback has a positive influence on learning outcomes [19] and plays an important role in collaborative processes. Participants get aware of how they affect other group members [37] and are more satisfied with the collaborative experience [23].

A moderator or teacher can provide this feedback, but especially in collaborative work settings this person might interrupt and disturb the working process. Group mirrors in contrast achieve a shorter feedback loop and can affect behavior in a more unobtrusive and subtle way by providing feedback integrated into the ambience and by using enjoyable forms of representation. However, complex visualizations that require participants' interpretation distract from the actual task. Feedback needs to be designed carefully in order to be easily and quickly understandable. Streng et al. [41] showed the advantages of metaphors in comparison to diagrams. These lead to more self-regulated behavior and are more popular.

We present *Groupgarden*, a metaphorical group mirror to support brainstorming sessions (see figure 1) and two user studies. *Groupgarden* visualizes individual activities as well as group performance to balance participation and to overcome known brainstorming problems. In a preliminary study, we validate the visualization of our group mirror to make

sure that it has the expected effects on performance and self-regulation. We therefore compared two brainstorming sessions: one session with group mirror and a second session as baseline without any feedback. We show that with *Groupgarden* (1) participation levels were more balanced with group mirror, (2) the adherence to particular brainstorming rules was facilitated and (3) the number of ideas did not decrease.

However, several characteristics of group mirrors can influence the effectiveness of the feedback. We want to look at one aspect in more detail: the placement. In the main study, we therefore evaluated the influence of the positioning of the feedback on group behavior. A version of *Groupgarden* adjusted for displaying it on a table was compared to the original version on the wall. Results reveal strengths and weaknesses of both positions. Feedback on a wall is conceived as less disturbing and less pressuring while feedback on a table seems to strengthen communication and collaboration. *Groupgarden* performs equally well in terms of balancing participation levels with a centralized and with a peripheral location.

RELATED WORK

Our work relates to the concepts of brainstorming, metaphors, group mirrors and the research on different display setups.

Computer-support for Brainstorming

As described in the introduction, brainstorming can suffer from negative effects such as *production blocking*, *free riding* and *evaluation apprehension* [14]. Several approaches and systems address these problems. Electronic brainstorming systems (EBS) can support remote collaborative creativity and can thereby decrease some of the problems: parallel input can prevent *production blocking* and anonymity can reduce *evaluation apprehension* [7, 9]. Despite the advantages of EBS, co-located brainstorming sessions are popular and are not likely to be completely replaced by EBS [11].

Other systems support face-to-face creative collaboration. *Firestorm* [6] assists both phases of brainstorming – storming (idea generation) and norming (idea categorization) – by providing the possibility to generate and group ideas on an interactive tabletop. Concurrent input is possible to minimize production blocking. To discourage free riding, each idea is colored according to the author. Hilliges et al. [20] combined an interactive table with a large wall display and compared it to paper-based brainstorming to derive a number of design guidelines such as using pseudo-physicality. These approaches focus on directly supporting brainstorming processes by providing adequate tools such as electronical post-it notes. Our approach is independent from the chosen tools (e.g. pen and paper, interactive tabletop) and instead supports brainstorming through ambient feedback.

The influence of feedback on brainstorming has for instance been studied by Paulus et al. [33]. They could show that participation levels of group members were affected by displaying information about the performance of other groups. Roy et al. [38] demonstrated that a constantly available public display anonymously depicting ideas of all group members can evoke social matching and therefore can lead to more ideas and more balanced participation in nominal brainstorming.

Group Mirrors and Ambient Displays

There are a number of group mirrors that aim to balance participation rates by different visualizations of feedback. *Second Messenger 1.0* [16] displays speaking times during problem-solving discussions in form of a diagram on a wall display, whereas *Second Messenger 2.0* [15] uses different kinds of visualizations on a tabletop. The authors found when displaying the feedback in real-time, over-participators decreased their participation, however under-participators did not contribute more. Another tabletop based system is *Reflect* [2] that mirrors participation levels in form of colored LEDs in collaborative learning scenarios. A user study comparing topic-based feedback with speaker-based feedback indicates that a more balanced participation could only be attained for group members who believed in a benefit of equal participation levels. Sturm et al. [43] developed a similar system, which displays, in addition to speaking times, eye gaze patterns that visualize the attention group members get from speakers and listeners. Results show a more balanced participation including contributions of over- as well as under-participators. *Meeting Mediator* [26] uses mobile phones and electronic sensing devices that collect and analyze social behavior (sociometric badges) to display feedback and can therefore also be used for remote collaboration. Brainstorming was one use case of the system, whereas they did not address rules and problems of brainstorming specifically. One of their findings was that dominant persons had negative effects on brainstorming.

More ambient feedback forms have been applied for instance by Rogers et al. [34]. They could show that people adapt their behavior (taking the stairs or the elevator) as result of the influence of ambient displays. Balaam et al. [3] showed that displaying feedback about nonverbal behavior can enhance rapport between participants. Schiavo et al. [39] compared overt directives in form of text messages with subtle directives using implicit information in form of visualizations inspired by the information decoration approach. In their work, a Kinect camera tracked gaze directions and thereby could detect participants that gained less attention than the others. They found indications that subtle feedback is more effective, if group members know about the meaning of the feedback.

Until now, only few group mirrors focus on supporting qualitative aspects. *Conversation Votes* [5] combines feedback about participation rates with anonymous votes. Streng et al. [41] used the compliance to a given collaboration script for learning as criterion for the quality of group processes. Two different types of visualizations have been compared in their work: an abstract group mirror in form of a diagram and a metaphorical group mirror. Metaphorical visualizations use objects and scenes similar to real life to transmit the information, which is embedded into attributes of the shown objects like size, color etc. The alternative to metaphorical visualizations are abstract visualizations, which do not have any real-world meaning, e.g. using bars or colored circles. The user study of Streng et al. [41] reveals the great potential of metaphorical visualizations, which can effectively influence group processes and at the same time provide feedback in a more unobtrusive way than a diagram.

Metaphors have proved to be effective in other scenarios, too [8]. *PeopleGarden* [45] visualizes participation on a message board. Flowers represent individual group members. The number of postings is visualized by colored petals and the height of a flower illustrates the time a participant has been involved. Lantin et al. [28] report that users of *FlowerGarden*, a system to support concept sharing representing group members as flowers, resulted in a competition for the prettiest and biggest flower.

Display Environments

There are several studies that explore the influence of different display settings on collaboration. Mandryk et al. [29] discuss seven different display factors, including orientation. Inkpen et al. [21] expose different assets and drawbacks: collaboration on horizontal displays feels natural and comfortable, while interaction with vertical displays can lead to more time-efficient working. The display environment can also have an influence on collaborative learning scenarios [42]. Rogers et al. [35] could show that in a problem-solving task more ideas were found and collaboration was more balanced on a horizontal display than on a vertical display. However, all these references examine interactive surfaces that in contrast to pure feedback systems provide the possibility to actively interact with them. So the question remains, if display orientation affects the efficiency of group mirrors. This aspect will be explored in more detail in the second study.

DESIGN AND CONCEPT OF GROUPGARDEN

Groupgarden is a metaphorical group mirror that displays feedback to a group during brainstorming. The prototypical implementation of *Groupgarden* provides two interfaces, one being the metaphorical representation used as feedback for the group, and another one used for a person controlling the system, which we call the 'control interface'. Both interfaces are implemented in Flash and communicate through a server. The control interface is used on a regular computer while the group mirror visualization is projected on a surface.

Design of Groupgarden

The findings of Streng et al. [41] demonstrate that metaphorical visualizations lead to better self-regulation than feedback in form of diagrams. Streng et al. used metaphors derived from nature to indicate the quality of argumentation: group members are represented by trees that flourish or lose their leaves depending on the quality of argumentation or by changing weather conditions (clouds appear and it starts to rain if the quality of argumentation reduces). Based on the advantages of metaphorical visualizations we decided to build on these findings.

Brainstorming is a continuous process for which an organic metaphor like a garden scenery seems appropriate. Firstly, flowers, trees and weather conditions are cross-cultural understandable to a high degree [10]. Secondly, a garden is normally a peaceful and non-threatening place that can be inspiring, what has been demonstrated by several artists [18].

Moreover, some of the related work also has shown for similar purposes that flowers and gardens are effective visualizations. In *Groupgarden*, the elements that transmit most information are flowers. This metaphor is simple and has an inherent legibility but can nevertheless visualize several changing aspects [17]. In nature, flowers normally change faster than trees depending on external circumstances such as weather conditions. Accordingly, in *Groupgarden* a tree represents group processes that are only observable after a certain time.

However, the use of metaphorical representations implicates a number of limitations. The complexity of the concept should equal the complexity of the visual representation [1]. Metaphors such as flowers and trees have a rich symbolic character that could impede direct mappings and could lead to wrong interpretations [17]. Additionally, the number of features that can be represented is restricted and a trade-off between information density and the "naturalness" of the metaphor is necessary, for example regarding the scalability of a metaphoric visualization. The choice of a specific design furthermore implicates or excludes particular use cases. The design of *Groupgarden* is appropriate for uncritical brainstorming sessions and seems especially convenient for children to learn rules of brainstorming or group work in general.

Concept of Groupgarden

The main principle of brainstorming is to find as many ideas as possible. To motivate group members to follow this rule, the group mirror displays the number of ideas everyone contributes. Each group member is represented by a flower. Figure 2a shows the group mirror in the beginning of the brainstorming: The flowers are all commensurate and the tree is bald. The more ideas a participant contributes, the more petals of the flower fill up. When all petals are colored, the flower reaches the next level: it grows and new unfilled petals appear. In figure 2b the left and the center flower are on the same level, the flower on the right is on a higher level.

To balance participation and reduce free riding, we developed a group mirror that provides feedback not only about individual but about group performance. The feedback is less comparative than the flowers and is intended to create a positive group experience and strengthen the common goal. We chose a tree for visualizing balance and overall number of ideas. As soon as all flowers reach the next level, the tree in the back starts to grow and leafs appear. That means that not necessarily all flowers need to be at the same level at the same time. As soon as the last flower reaches a certain level the tree grows according to that level. Figure 2c shows an extremely unbalanced brainstorming. As the flower in the middle is on the first level, the tree did not grow. Figure 2d in contrast shows brainstorming with balanced participation.

This combination of individual feedback (in form of flowers) and aggregated feedback (in form of a tree) is a new approach to increase the motivation of a group. This includes a "gamification aspect". Using gaming elements in a non-gaming environment [13] can increase motivation regarding the respective task [4, 12, 30]. In *Groupgarden*, group members are represented by avatars, namely the flowers. A common goal, the growth of the tree, is defined. We believe that the
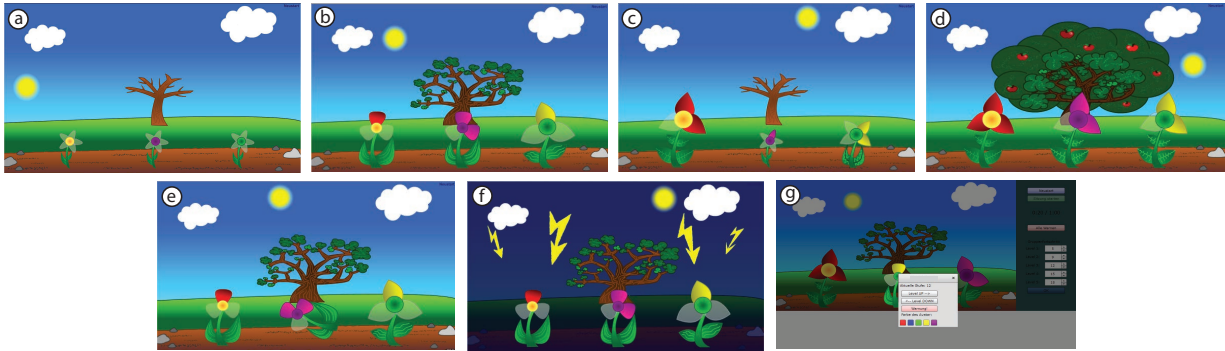
Figure 2. Different states of the group mirror: a) Status of the group mirror in the beginning of a brainstorming session with three participants, b) possible visualization during a brainstorming session, c) extremely unbalanced brainstorming session, d) balanced brainstorming session, e) individual warning, f) group warning and g) the control interface.

gamification of brainstorming rules can increase group members' motivation to adhere and learn these rules.

As group members should not interrupt others and should not judge ideas (neither in a negative nor positive way), an individual warning can appear to remind the concerned participant of the brainstorming rules. This is realized by rotating the flower that represents the participant for a short time (see figure 2e). We expect that the addressed group member knows, why the warning is shown – due to interruption or due to judgment. As the natural "behavior" of flowers (e.g. growing) is very unimposing, we opted for an unrealistic movement to enable peripheral perception of the warning. To remind the group to stay on topic, flashes can temporarily change the appearance of *Groupgarden* (see figure 2f). Again, we build on the findings of Streng et al. [41], who also used a flash when group members interrupted each other. They showed that the deficient behavior was corrected faster with a warning than without. An additional feature of *Groupgarden* is the sun (moving from left to right over the scene on its orbit), which serves the purpose of displaying the elapsed and remaining time of the brainstorming session.

The first version of the *Groupgarden* interface is designed for displaying it on a wall. The adaption of the visualization for displaying it on a table is depicted in figure 8a. We compared both versions in the main study.

Control Interface

The visualizations of the group mirror can be changed through the control interface. This can be done by a moderator or, as in our study, by a Wizard of Oz [25]. In this approach, users think that they work with a fully implemented system while actually a person controls (parts of) the system. An outlook on automated assessment of qualitative aspects of collaboration will be presented in the discussion.

In our case, the experimenter operated the group mirror while participants were told that the computer only served the purpose of taking notes. The experimenter could start and end the session, enter the number of ideas of each person and could send warnings. Figure 2g shows a screenshot of the control interface. When clicking on a flower, a window pops up that makes it possible to change the settings for that particular flower. The number of ideas can be increased by one at a time so that another petal of the flower gets filled. With the panel on the righthand side, the session can be started and ended, the elapsed and the total time are displayed and the button for prompting group warnings is positioned here.

PRELIMINARY STUDY: GROUP MIRROR VS BASELINE

We conducted a user study to validate the influence of *Groupgarden* on co-located collaborative brainstorming.

(Q1) Does *Groupgarden* facilitate the ability of self-regulation of participants during brainstorming?
(Q2) Does *Groupgarden* support rules and does it reduce problems of brainstorming?

Participants

Three participants took part in each brainstorming session. We conducted ten sessions with 30 people in total (40% female). The average age was 24. 73% were students, 20% were PhD students and 7% had another profession.

Method

The study was organized as a quasi-experiment [40] in a lab using a one-factorial design. Two conditions were compared within subjects (i.e. the same group brainstormed under both conditions): a baseline condition without any feedback (neither by a system nor by a moderator) and a group mirror condition using *Groupgarden*. The order of the two conditions was counterbalanced, i.e. five groups started with the baseline and five groups with the group mirror condition. However, we used a quasi-experiment as some variables such as prior knowledge about the brainstorming topics or group composition cannot be completely controlled.

Setting

During the brainstorming, the three participants were seated on revolving chairs in front of a wall (without a table). The group mirror was projected on the wall in front of the group. Participants could choose their viewing direction and sitting position by themselves. They could position themselves independently in front of the display, either more side-by-side or more face-to-face. Inkpen et al. [21] describe the tradeoffs: users sitting side-by-side have a good view on the shared display while a face-to-face setup facilitates conversation.
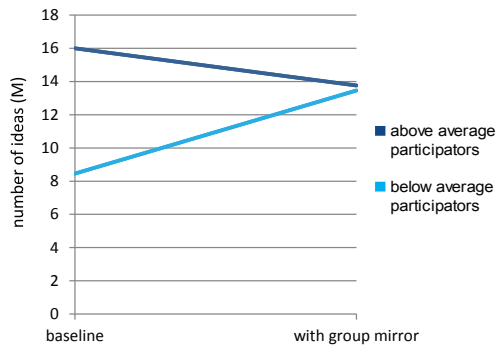
Figure 3. The number of ideas was more balanced in the group mirror condition than in the baseline condition.
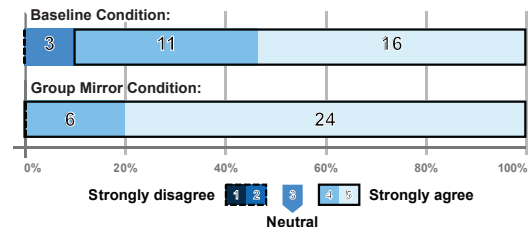

Figure 4. The answers to the statement "The other group members attempted to actively take part in the brainstorming." show that in the group mirror condition group members estimated the others to be more actively involved in the brainstorming.

Task and Procedure

Before the two brainstorming sessions, the experimenter explained the scope of the study and the brainstorming rules. Moreover, the group mirror was introduced in the group mirror condition. Two topics were chosen: (1) *What could a commercial for a new tablet computer look like?* and (2) *What could a commercial for a new caffeinated soft drink look like?* Both topics were alternated between conditions (group mirror and baseline). The topics have a creative problem solving aspect and do not need any special precognition. Each topic was discussed for 15 minutes. After a brainstorming session, the participants were asked to fill out a post-questionnaire. After both sessions, a final questionnaire had to be filled out and a semi-structured interview was held.

Results

We evaluated the study using the answers of the questionnaires, the statements of the interviews and the qualitative observable and quantitative measurable information of the video recordings. The answers from the questionnaires on five-point Likert scales were compared using the Wilcoxon Signed-Rank Test. The quantitative measurable data was compared using t-tests. All statistical tests were applied on a 5% level of significance.

(Q1) Does *Groupgarden* facilitate the ability of self-regulation of participants during brainstorming?
The main goal of combining individual feedback in form of flowers with aggregated feedback in form of a tree was to equalize the number of ideas. We used a Wizard-of-Oz approach to display the number of ideas which means that the coding of what counts as an idea had to be done in real time. We defined an idea as novel contribution that is related to the topic. To assess the reliability of our coding, another person coded two brainstorming sessions (with group mirror and baseline) of one group with the aid of the video recordings. We used Cohen's kappa as a measure of reliability. Results show an accuracy of .80, i.e. substantial agreement.

To assess whether the number of ideas was more balanced between group members in the group mirror condition compared to the baseline, participants were categorized as above and below average. These categories were determined by postprocessing the data, hence the group members did not know their categorization. We took the baseline as basis for the categorization. Therefore, we calculated the average number of ideas across all groups ($M = 38.2$) and divided it by three to get the average number per participant ($M = 12.7$). Accordingly, group members with at least 13 ideas were categorized as above average (17 of 30 group members) and participants with 12 or less ideas as below average (13 of 30 group members). The statistical analysis shows that above average participants contributed significantly less ideas in the group mirror condition ($M = 13.76$, $SE = .48$) than in the baseline ($M = 16$, $SE = .74$), $t(16) = 3.27$; $p < .005$; $r = .63$, while below average participants contributed significantly more ideas with group mirror ($M = 13.46$, $SE = .51$) than without ($M = 8.46$, $SE = .69$), $t(12) = -5.36$, $p < .0001$, $r = .84$.

In figure 3, the number of ideas of over- and underparticipants is displayed, and visually shows that the quantity of ideas is less scattered between participants in the group mirror condition. Explanations stated in the interviews were for example:

"I didn't want to be the one with the ugliest flower and bugger up the growth of the tree." (Group1, Participant 1)
"You restrain yourself more if you see that your flower is already bigger. I stopped talking then and thought: 'let the others talk' (G4, P2) "

Two other participants relativized that statement:

"If the others don't come up with ideas at that moment I would still go on talking because then again you inspire the others." (G1, P2)
"The system would not restrain me from saying something, if I had a really good idea" (G1, P1)

These quotes emphasize that under- as well as over-participants are motivated to balance their participation and that "good" ideas are nevertheless revealed.

In the final questionnaire, 73% of the participants stated that they perceived participation levels of all group members more balanced with *Groupgarden*. 91% declared that they were more motivated to take part in the brainstorming with feedback. The results of the post-questionnaires indicate that participants did not perceive their own motivation differently in the group mirror condition compared to the baseline. At the same time, group members rated the efforts of others to actively take part in the brainstorming stronger in the condition with feedback, $z = -2.67$, $p < .05$, $r = -.6$ (see figure 4). Two participants stated that they were more motivated because of the playfulness of the system.
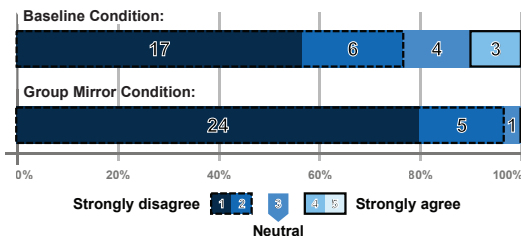
Figure 5. The answers to the statement "Group members were often criticized because of their contributions." show that participants estimated the amount of judgments higher in the baseline condition.
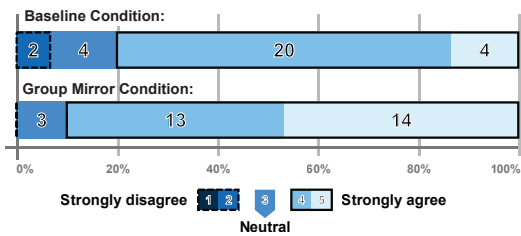

Figure 6. Answers to the statement "The group could effectively conduct the brainstorming." show that participants estimated the effectivity of the brainstorming better with *Groupgarden*.

(Q2) Does *Groupgarden* support rules and does it reduce problems of brainstorming?

Next to balancing participation levels, *Groupgarden* pursues the goal to support brainstorming rules. One important rule is to focus on quantity rather than quality of ideas. The number of generated ideas in the group mirror condition ($M = 40.9$, $SE = 1.3$) was slightly higher than in the baseline ($M = 38.2$, $SE = 3.2$), however without statistical significance. As not every contribution but only new ideas are reflected in the group mirror, participants seemed not to just repeat ideas to get positive feedback but to generate new ideas:

"I found that the second time [baseline] we somehow again and again discussed the same topics. I think the first time [group mirror condition] we have more productively addressed new ideas because you wanted to get bigger [flowers]." (G6, P3)

We counted the number of interruptions in both conditions to find out, if participants remembered not to interrupt each other when receiving warnings. In the group mirror condition, these warnings were needed rarely. For both conditions we could not detect any interruptions that were not part of the natural course of a conversation (e.g. two persons starting to speak at the same moment).

Equally, the adherence to the rule "do not judge ideas" was measured by counting the number of judgments in both conditions. In the group mirror condition, judgments only occurred three times ($M = .03$, $SE = .21$). In the baseline condition, 15 situations occurred in which group members judged others' ideas ($M = 1.5$, $SE = .34$), $t(9) = 4.81$, $p < .001$, $r = .85$. Answers of the post-questionnaires show that participants assessed the number of judgments slightly higher in the baseline condition than in the group mirror condition, $z = -2.62$, $p < .01$, $r = -.59$ (see figure 5). One participant stated:
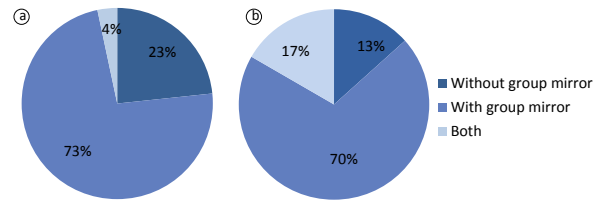

Figure 7. a) Preference of brainstorming with group mirror or without group mirror and b) contentment with the results of the brainstorming session with and without group mirror.

"With the feedback system I took care to completely leave out any criticism." (G4, P1)

Similar to individual warnings, group warnings (lightning) to support the rule to stay on topic were rarely needed in the group mirror condition. In total four group warnings were displayed to four different groups ($M = .04$, $SE = .16$). In the baseline, digressions from the topic occurred seven times, thereof three times in one group ($M = .07$, $SE = .30$), without statistical significance between the conditions.

In the post-questionnaires, participants rated the effectivity of the brainstorming significantly better in the group mirror condition than in the baseline, $z = -2.37$, $p < .05$, $r = -.53$ (see figure 6). In the final questionnaire, a majority of 74% preferred the brainstorming session with group mirror (see figure 7a). For 70%, the results of the brainstorming session with feedback were more satisfactory (see figure 7b).

The design of *Groupgarden* was well received. 93% liked the way the information is visualized (7% did not have an opinion regarding the design). The *"intuitive"* and *"simple"* character of the garden metaphor was on the one hand stated as a positive aspect:

"You know immediately what it means" (G1, P2)

On the other hand, concerns were raised and a limitation regarding the usage scenario was mentioned:

"It is still designed childlike." (G4, P2)
"It depends, I wouldn't give it to a businessman, but for us it was actually pleasing." (G5, P3)

Finally, the seating arrangement was examined. Six groups positioned themselves in the form of a triangle, so that all participants faced each other. As a result, the group mirror was only visible in the periphery for two participants. Four groups sat down in a row (see for instance figure 1) so that they had a good view on the visualization but could not face each other perfectly. Two persons of groups that positioned themselves in a row stated:

"I found the seating arrangement a bit difficult. Now [in the baseline] I found it much more pleasant that we could sit in a circle and look at each other." (G2, P2)
"It would be cool if we could have the visualization more centered, or on all walls." (G9, P2)

VISUALIZATION OF GROUPGARDEN ON A TABLE

The seating arrangement came up as a concern in the first study and participants suggested a more centralized visualization. As previous research (e.g. [21, 29, 35, 42]) already
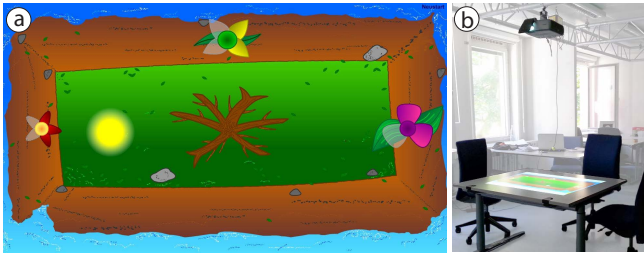
Figure 8. a) *Groupgarden* **visualization adapted for displaying it on a table. b) Study setup for the table condition.**

revealed that the display environment can have an influence on group work, we developed a table version of *Groupgarden* to find out, if the location of the feedback influences self-regulation of participants and efficiency of brainstorming (see figure 8a). As the group mirror environment is not interactive and does not contain any text, problems like arm fatigue or orientation problems do not occur. The visualization contains the same elements and the same functionality as the version on the wall. Sizes and transitions remain the same. The graphical visualization was adapted to provide such an aerial view of the garden in contrast to the lateral view in the wall condition. A mirror was attached to the front of the video projector to enable the projection on the table (see figure 8b).

MAIN STUDY: WALL VS. TABLE
We examined the influence of the positioning of the feedback in more detail in a second study.

(Q1) Does the location of *Groupgarden* influence the ability of self-regulation of participants during brainstorming?
(Q2) Does the location of *Groupgarden* influence the adherence to brainstorming rules and occurrence of problems?

Participants
Equally to the first study, three participants conducted each brainstorming session together. These were other participants than in the preliminary study. Eight sessions took place, with a total of 24 people (46% female) and an average age of 25 years. 75% were students, 12% PhD students and 13% had another profession.

Method
We conducted the study as a quasi-experiment in the lab with a one-factorial design and two conditions that we compared within subjects: a setup similar to the first study with the feedback of *Groupgarden* on a wall and a setup with an adjustment of *Groupgarden* on a table. The order of these conditions and the topics were counterbalanced. The seating arrangement was predefined: the participants were placed around a square table so that one person faced the wall and the other two faced each other with the wall in their periphery.

Procedure
The procedure of the study was equal to the first study: brainstorming sessions took 15 minutes and were followed by post-questionnaires, a final questionnaire and a semi-structured interview. The evaluation was again based on these questionnaires, interviews and on video recordings.

Results
The answers from the questionnaires on five-point Likert scales were compared using the Wilcoxon Signed-Rank Test. The quantitative measurable data was compared using t-tests. All statistical tests were applied on a 5% level of significance.

(Q1) Does the positioning of *Groupgarden* influence the ability of self-regulation of participants during brainstorming?
In a first step we looked at the balance of the number of ideas in both the wall- and the tabletop-condition. We classified above and below average participants accordingly to the first study, this time with the wall condition as basis. The average number of ideas was 12.54, so that group members with more than 13 ideas were categorized as above average (13 of 24 group members) and participants with 12 or less ideas as below average (11 of 24 group members). Results do not show any significant differences of the quantity of ideas of above average participants between the wall condition ($M = 15.46$, $SE = .45$) and the table condition ($M = 15.77$, $SE = .83$). Furthermore, we could not find significant differences of the number of ideas of below average participants between the wall condition ($M = 9.09$, $SE = .5$) and the table condition ($M = 9.73$, $SE = 1.45$).

The outcome that both locations of feedback support self-regulation in a similar way is supported by the results of the questionnaires. In the final questionnaire, 37% rated the statement "I was more motivated in the table setup" with "agree" or "strongly agree", 46% disagreed or strongly disagreed with that statement and 17% did not have an opinion.

(Q2) Does the location of *Groupgarden* influence the adherence to brainstorming rules and the occurrence of problems?
To evaluate, if the rule to focus on quantity was supported more effectively by one of the two display environments, the number of ideas was compared between both conditions. There were no significant differences between the wall condition ($M = 37.63$, $SE = 3.47$) and the table condition ($M = 39$, $SE = 3.77$).

Similar to the group mirror condition in the first study, warnings had to be used rarely, consequently we could not detect any differences between the two feedback environments. In the final questionnaire, we asked the participants, which display setting they preferred. 54% preferred the feedback on the table, 42% the version on the wall (and 1 participant did not have any preference). We asked participants about the reasons for their decisions. The table version was preferred mainly because it was better visible (mentioned by 29% of the participants), it was easier to hold eye contact with the other group members (18%) and it was better integrated in the brainstorming process (13%). Furthermore, collaboration and communication were rated better (13%) than in the wall version. One of the participants stated about the feedback on the table:

"It obviously facilitated face-to-face communication, as you have the feedback system and the other group members in your range of vision at the same time. Thus it was easier for me to hold eye-contact." (G1, P1)

The feedback on the wall was preferred mainly because it was less distracting than the feedback on the table (25%). Other reasons were better visibility for those who were sitting directly in front of the wall (8%) and less pressure, as the wall feedback can be ignored more easily (4%). The reasons partly overlapped with the reasons that were mentioned in favor of the table, but were rated differently, as for instance this statement of a participant who preferred the wall feedback shows:

"There is less pressure on you through the wall feedback. You are more aware of the feedback on the table and a competition arises to overtake the others (...)" (G3, P3)

When asked how motivating the feedback was, 10 preferred the table version, 8 the wall version and 6 estimated both as equally motivating. One reason for preferring the table was:

"The group was rather more closed and the collaboration was a bit better, but only a bit more motivated, because I was motivated with both systems. " (G1, P1)

As the seating arrangement was predefined in this study, we examined the influence of the seating position in more detail. We therefore focused on the differences between the person facing the wall and the other two group members facing each other. Results do not reveal any significant differences regarding the generation of ideas. As there was no significant difference between the person sitting on the left ($M = 12.63$, $SE = 1.34$) and the person on the right ($M = 12.5$, $SE = 1.39$), we calculated the mean of the number of ideas of these persons to compare it to the number of ideas of the participant facing the wall. The average number of ideas of the group members sitting in the middle ($M = 12.75$, $SE = 1.21$) is not significantly different compared to the other two group members ($M = 12.56$, $SE = 1.33$). However, two participants who faced the wall preferred the group mirror on the wall because they *"had a better view" (i.a. G8, P2)* and could *"more easily take an occasional peek" (G3, P2)* on the group mirror than in the table condition.

DISCUSSION

Groupgarden is a metaphorical group mirror to assess, which influence this kind of peripheral feedback has on brainstorming sessions. We conducted a lab experiment to compare brainstorming with metaphorical feedback to a baseline condition without feedback and could show that *Groupgarden* facilitated the self-regulation of the group and could support particular rules of brainstorming. We could not find any effect that impaired the brainstorming process. On the one hand, we strengthen established results and on the other hand introduce new concepts in the brainstorming context such as qualitative and metaphorical feedback and the combination of individual and aggregated feedback.

We observed that the number of ideas was more balanced in the group mirror condition while the total number of ideas slightly increased (although not significantly). We assume that especially the intuitive metaphorical visualization and the combination of both, individual feedback about the number of ideas as well as the feedback of group performance, encouraged group members to participate in a more balanced way. However, this implies that above average participants

contributed less ideas in the group mirror condition than in the condition without feedback. As the overall number did not decrease and below average participants increased their contribution, we consider this as a positive effect. Free riding is less likely and it furthermore admits group members that are shy or not well integrated in the group the possibility to state their ideas, so that the perspectives of all participants are included in the idea generation process. Additionally, we could show that participants judged the ideas of others less often. We conclude that the garden interface has a positive effect on motivation mostly through its intuitive and easy understandable metaphors and its playful character.

The second study revealed that centralizing the feedback does not improve brainstorming processes. Neither the *Groupgarden* visualization that was displayed on a wall nor the adaption of *Groupgarden* on a table outweighs the other one. There were no significant differences regarding the number of ideas and balance of ideas within groups. However, both environments have assets that should be taken into account when designing a feedback system. Results of the study indicate that peripheral feedback such as a visualization on a wall is less disturbing and puts less pressure on the group members than a representation in the center of the group such as on a table. In contrast, a centralized group mirror may ease collaboration and communication.

One drawback of lab studies is that participants' behavior can be affected by the artificial situation. We could not measure any interruptions during the brainstorming and few deviations from the topic. We expect this behavior to be different in a real world scenario in which group members are not observed by a video camera and mostly have some relationship to the discussed topic. However, as the brainstorming sessions in each individual study were carried out under the same conditions, an imbalanced bias is unlikely regarding the comparison of them.

Groupgarden provides feedback about qualitative aspects such as ideas. As a consequence, a qualitative analysis of the discussion is necessary, as not every contribution is coincidentally a new idea. In *Groupgarden*, a Wizard of Oz rates the performance of the group and modulates the displayed feedback through the control interface. Automated assessment of qualitative aspects of speech are already possible for written dialogues. Rosé et al. [36] for instance used computational linguistics to automatically analyze collaborative learning processes by using written discussions to develop and refine automated classifiers. Combining a speech recognition tool with such an automated analysis tool seems possible and can enable automated assessment especially for discussions about general topics. For more complex and detailed problems a neutral moderator can manually evaluate the quality of the contributions and in doing so provide feedback in an unobtrusive and subtle way without interrupting the group.

CONCLUSION

In this paper we presented *Groupgarden*, an ambient and metaphorical feedback system to support brainstorming sessions. As the conceptual system of humans is mostly of

metaphorical nature [27], we believe that this form of feedback can improve creative processes. We contribute insights on the influence of a metaphorical group mirror on self-regulation during brainstorming and on adherence to the rules of this particular creativity technique. For that purpose, a visualization providing feedback to a group in form of metaphors, such as flowers representing the individual group members or a tree visualizing group performance, was compared to a baseline, a brainstorming session without any feedback.

Results show that the number of ideas of the individual group members is more balanced with the feedback of the group mirror, while the overall number of ideas did not decrease. Furthermore, group members judged ideas of others significantly less often when the group mirror and corresponding warnings were shown. A majority of 73% preferred the brainstorming with peripheral feedback over brainstorming without additional support. These results confirm the results of previous research that demonstrate the influence of feedback on brainstorming (e.g. [33]) and add insights about the impact of a novel feedback approach consisting of a qualitative feedback in form of a playful metaphorical visualization on specific brainstorming rules.

Having shown that the feedback of *Groupgarden* can successfully influence brainstorming groups, a more detailed analysis is needed. As a first step, we studied the influence of the physical location of *Groupgarden* on group behavior and learned that feedback in the periphery of group members has similar effects as more centralized feedback. However, both environments have other advantages and drawbacks such as the amount of disturbance and communication, providing a relatively rich design space which can be optimized for other design goals while keeping the positive effect of the group mirror intact.

The presented system combines several approaches that have the common goal to support brainstorming. *Groupgarden* is built on the findings of others, for example in choosing metaphorical visualizations [41]. Other parts apply new concepts such as the group feedback that is dependent on the balance of individual performance. We found that metaphorical group mirrors can procure a meaningful support for brainstorming sessions. To investigate the generalizability of the concept and to expose the influence of the individual components of *Groupgarden* we plan to conduct further studies: on the one hand studies 'in the wild' and on the other hand studies that examine individual aspects in detail, for instance by comparing different metaphorical visualizations. As group dynamics such as free riding can also be dependent on the group size (see e.g. [44, 22]), investigating the effects of *Groupgarden* on larger groups is an important next step.

Groupgarden is a first approach towards supporting collaborative creativity through metaphorical feedback. In the long term, we can imagine intuitive group mirrors being used in schools to teach children how to work together effectively or more ambient forms of group mirrors such as luminous objects being embedded in meeting rooms to support experienced collaborators without disturbing the group.

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