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IdeaVis: A Hybrid Workspace and Interactive Visualization for Paper-based Collaborative Sketching Sessions

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ABSTRACT
In this paper we describe IdeaVis, a novel approach for supporting co-located sketching sessions. Our system is based on digital pen & paper for augmenting the traditional paper-based workflows of sketching sessions. An additional focus & context visualization is used to support creative facilitators in exploring and examining the design activity, thereby increasing awareness over inhibitors that may impede the success of such sessions. The general applicability of our approach was confirmed in a user study with creative professionals. We conclude that live design activity visualizations can provide benefits for controlling typical inhibitors of creative group work without the need to change traditional workflows.

Author Keywords
Creative group work, idea-generation, sketching, digital pen & paper, design activity visualization

ACM Classification Keywords
H.5.3 Group and Organization Interfaces: collaborative computing, computer supported cooperative work

General Terms
Design, experimentation

INTRODUCTION

Designers frequently collaborate on problems and solutions during early phases of the design process. Within design activities, collaboration can potentially lead to more creative ideas and better solutions [22]. When working in a group, designers are able to generate new concepts by not only reflecting and modifying their own ideas, but also each other's ideas. This re-interpretative cycle is often considered a key ingredient of creativity [18]. Several studies have shown that groups can produce more and better ideas than individuals, however, under the premise that inhibitors are minimized [15]. Social factors, like *evaluation apprehension*, *production blocking* or *free riding* (social loafing) have been shown to have dramatic effects on a group's performance in co-located settings [22,15]. Furthermore, *design fixation* effects can have negative impacts on the quality of a creative group activity [17]. Social dynamics, like the influence of strong personalities or gatekeeping may also have an influence on the participation of individual team members. Consequently, professional practitioners tend to use structured methods and techniques that moderate these hindrances [9]. Creative sessions may also be facilitated by a professional who directs the group's activity with the goal to minimize the negative effect of these factors. This way, not only social inhibitors, but also organizational issues, like time, breaks and tasks can be controlled for making idea generation meetings more efficient.

Despite recent developments in ubiquitous computing technology which blends in with the physical environment, many digital design tools replace existing physical practice by digital means, thereby changing not only the methods that can be applied in the group, but also traditional workflows that are used to cope with social inhibitors. Often, these tools do also not care for a session facilitator, thereby limiting the control such a trained professional can have over the group activity. As a result, designers frequently consider technology to be harmful in their collaborative work environments and stick to traditional media [3]. By using physical artifacts and by harnessing the spatial properties of the environment, they can make use of rich forms of expression like body language, facial expressions and the immediacy of verbal communication that are crucial for expressing their creativity [21]. Paper sketches for example can easily be shared on large whiteboards or spread out on tables for comparison, discussion and annotation. Similar accessibility and flexibility is yet unmatched with most digital tools. However, when working with traditional tools only, designers give up on potential benefits in using digital media such as the ease of documentation, sharing and reuse of design artifacts or session histories. Both strengths and limitations of material practice point to the need for an integration of computational functionality with the physical, social and spatial ecology of collaborative design activities.

In this paper we describe the design of IdeaVis, a novel approach for supporting paper-based sketching sessions with a *hybrid workspace* and *interactive design activity visualizations*. The system combines digital pen & paper with digital displays that can be used by both designers and creative facilitators to augment idea generation and

synthesis. Our approach is grounded in a reality-based methodology which argues for building upon the knowledge and experiences of people in the "real world" [11]. Thereby, we respect that people's natural behavior such as physical, social and bodily interactions are highly practiced and robust and thus require little effort to learn and perform. Due to the particular challenging characteristics of creative group work, we believe that a sensitive and subtle deployment of technology is required. We therefore consider "power vs. reality tradeoffs", with the goal "to give up reality only explicitly and only in return for other desired qualities" [11]. In our design we strive for a balance between the power of the interface and its level of reality. For a more detailed description of our design methodology, see [5].

Figure 1. IdeaVis is a hybrid workspace and interactive design activity visualization for paper-based sketching sessions.

RELATED WORK

Our work relates to research in computing environments for co-located creative group work. In the following, we will describe the relation of our approach to some of these systems.

Entirely digital environments like i-LAND [20] mix interactive surfaces, like tables, walls and mobile devices for supporting fluent creative collaboration and for easing the transfer of information across devices. TEAM STORM [6] combines multiple Tablet PCs with an interactive whiteboard for supporting the management of multiple ideas within collaborative sketching sessions. BrainStorm [10] employs multiple pen-operated displays to support creative problem solving processes. Some of these digital tools explicitly address social factors as a part of their system design [6,10]. The tools however entirely replace traditional practices, thereby requiring the exclusive use of digital modalities. Compared to our approach, they lack support for paper-based sketching techniques and do not explicitly care for facilitators.

Hybrid digital tools such as The Designer's Outpost [12] combine physical paper with interactive displays. Thereby, physical and digital representations are bridged to support the brainstorming, documentation and sharing of ideas. Vision-based systems such as Pictionaire [8] take a similar approach, using overhead image capture and projection to merge physical artifacts with digital annotations. Paper-based support for sketching was also successfully used in several other systems such as the Diamond's Edge [2] and the Nice Discussion Room [7]. Like our system, these tools integrate digital pen & paper with large displays or interactive tabletops for supporting work with material paper artifacts or for augmenting these artifacts with digital functionality. However, our system takes a different approach, caring for a specific sketching method and workflow, social factors and a facilitator. IdeaVis can also be considered more subtle, not requiring the use of technology but offering it in an optional way for augmenting practices.

Our system makes use of interactive visualizations for augmenting awareness and communication abilities of facilitators. Such functionality has not yet been explored in the context of paper-based sketching sessions. Yet, it shares some goals with The Designer's Outpost, which explored a design history functionality that allows capturing and replaying web-design sessions [13]. Our approach extends such functionality toward live content-based analysis and interactive visualization that can be used by facilitators during the session. The EDC (Envisionment and Discovery Collaboratory) [1] also employs a dedicated reflection display in the urban planning context. Thereby, it supports an expert in directing the session. Yet, the system is not oriented toward the support of traditional paper-based design practices, like sketching sessions.

We may summarize that a subtle, reality-based support for specific sketching methods and support for session facilitators is worth exploring. Our system was designed to close the identified gaps by offering support for the workflows of traditional paper-based sketching techniques and by explicitly supporting the role of creative facilitators. As design decisions are often made implicitly, we also seek to make our tradeoffs between physical practice and digital tool support more explicit than other researchers.

ANALYSIS

In the following we describe an analysis of sketching practice through a literature review, observations of paper-based practice and recommendations of a professional creative facilitator. The knowledge gained from this analysis was used for identifying tradeoffs for the design of our system.

Collaborative Sketching Activities

Idea generation meetings are commonly practiced early in the design process to generate first ideas or solutions to a design problem. During this activity, members of a design team work collaboratively toward a common understanding of the design space. Some of the typically employed methods by creative professionals can be classified as "brainstorming" or "sketching" techniques [9]. While brainstorming methods focus on the production of a large number of unique ideas through limitations on words or short sentences, sketching methods are more directed

Issue	Production Blocking	Evaluation Apprehension	Free Riding	Fixation Effects
Method	Externalizing ideas should be possible anytime	Annotations instead of verbal commentary allow for reducing identification	Each participant should have the chance for explaining ideas	Warm-up activities Re-interpretation activities
Tool	Externalizing material should be easily accessible Provide simple tools for rapid externalization	Reduce identification by providing identical stroke color Provide individual workspaces for private work	Allow for identification on demand only Make individual contributions visible on demand	Make shared artifacts visible and accessible to the group
Facilitator	Allow for individual work	Make participants feel comfortable and appreciated	Stimulate contributions by involving passive participants	Invite production of new ideas Emphasize exploration or re-interpretation of selected ideas

Table 1. Approaches for addressing typical inhibitors of social creativity, partly based on [15,16,17,22].

toward the refinement and detailed discussion of ideas through externalization and visualization [16].

The productivity and efficiency of such a group activity is generally determined by social dynamics, the design knowledge of participants, the adequateness of employed methods, the physical or digital tools used, and the influence of a creative facilitator [15,16]. As emphasized in the beginning of this article, social dynamics may have the most dramatic effects on the success of creative group work. Well documented inhibitors are: *production blocking* (ideas cannot be externalized rapidly), *evaluation apprehension* (fear of judgment), *free riding* or *social loafing* (relying on others to do the work) and *fixation* (keeping fixed on early ideas) [17,22]. A creative facilitator may have influence on these dynamics as he may steer the activity through interactions with the participants. Nevertheless, methods and tools should also be designed as to cope with these issues. In Table 1 we summarized common approaches based on our research and that of others for addressing these inhibitors regarding the use of methods, tools and facilitators.

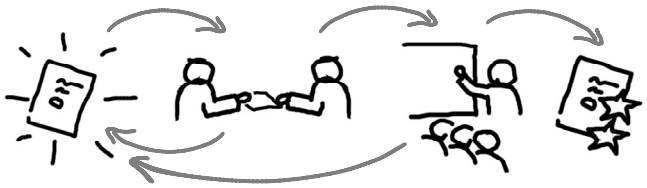

Figure 2. Workflow and phases of the brainsketching method.

Collaborative sketching as a design method can be practiced in myriad ways. However, studies have shown that sketching activities should be integrated into the idea generation process in a careful way [16]. Van der Lugt therefore developed the structured technique "brainsketching", "an idea generation technique that may be better suited for incorporating sketching in creative problem-solving" [16]. The method, which is based on four phases, is particularly designed for coping with the described inhibitors by a well-defined workflow and procedure. Brainsketching encompasses four basic phases (see Figure 2) that are iteratively conducted during group sessions: 1) *Individual externalization* (ideas are visualized with sketches and annotations), 2) *Sharing and annotating* (ideas are shared and annotated with text without verbal discussion) 3) *Gathering and Presenting* (ideas are presented and discussed in the group) and 4) *Rating* (ideas are rated according to relevance). The procedure iterates between the first and second phase until the flow of ideas reduces and between the third and first phase for re-interpretation and annotation of each other's ideas. Thereby, the method emphasizes refinement and re-interpretation over quantity of ideas. A facilitator may control the proceeding of the method by initiating phase transitions, by emphasizing or removing ideas, by adding annotations and by directing the discussion toward his particular goal.

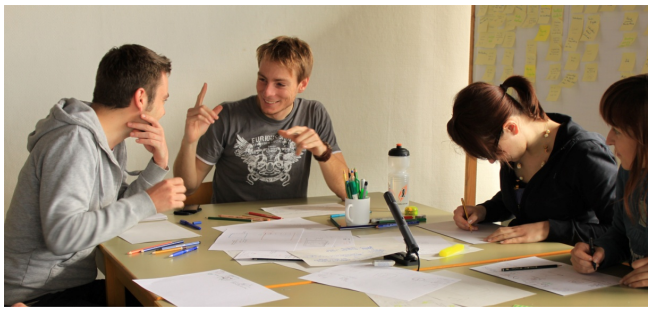

Figure 3. An observation of traditional brainsketching sessions revealed the importance of material and bodily aspects.

Observation of Traditional Practice

In order to learn more about the actual paper-based practice of collaborative sketching, we conducted an observation of brainsketching sessions. The observation was embedded into the practical part of an interaction design course. Overall, we observed four groups of novice designers (N=20, 5 each) in sessions that lasted between 1.5h and 2h. The groups were given traditional material and tools such as paper sheets, whiteboards, tables, pin boards and different pens. The rating of ideas was conducted by adding small adhesive dots to the paper. The sessions were also directed by a facilitator. With two researchers we collected material in the form of video recordings and structured observation notes. Our qualitative analysis was guided by the Reality-based Interaction (RBI) framework [11].

Thereby, we especially focused on the social, bodily and environmental behavior of participants. In the following, we will briefly describe our results and relate them to findings of other researchers.

Throughout all groups, we observed consistent use and appropriation of the provided workspace. The main workspace (table) was divided into different territories, such as private, semi-private and shared areas. Participants seemed to have a need for working privately in a protected area. The workspace division was accompanied with transfers of artifacts between these areas. This finding is along the lines of literature about evaluation apprehension [22], tabletop territoriality [19] and also with findings by a study conducted by Hailpern et al. [6]. Participants preferred the use of the table instead of the pin boards for sharing ideas. This behavior is partly due to the brainsketching technique in which ideas are annotated by passing them around. However, it limits visual accessibility of artifacts to the group. Nevertheless, we also found that paper triggers certain interactions like grabbing, turning and skipping that make collaboration fluent. This finding is in line with a study reported by Cook et al. [3], which found that the affordances of paper artifacts are valuable for design work. We could also not identify any occurrences of production blocking with the use of paper artifacts since we frequently observed rather rapid externalizations.

An especially frequent behavior was the use of gestures during presentation and discussion. We found that deictic gestures were an important form of implicit communication for the purpose of getting attention from others, for highlighting specific ideas, for emphasizing dynamics and motion within a sketch or to focus on certain parts of an idea. This finding is in line with an ethnographic study reported by Vyas et al. [21] on the use of body in design practice. Although gestures were often accompanied with verbal discussion, we again observed that the rather small size of the paper material was hampering accessibility and visibility of the ideas to all members of the group, even when artifacts were pinned to a shared surface. This led to participants sometimes missing crucial points of the discussion. As a result, we could notice several instances of free riding and fixation that we can at least partly attribute to a deficit in group awareness and lack of involvement of some participants.

Needs of a Professional Creative Facilitator

As described earlier, a facilitator may control the workflow and procedure of sketching sessions for the better. During our observation we found that some inhibitors are hard to control due to the dynamics and different personalities such a session may have. Therefore, we turned to a professional creative facilitator to learn more about his work and his needs. We were able to meet twice with a trained professional working within the innovation lab of a large German automotive manufacturer. With over six years of experience in directing creativity workshops on a professional level he was able to share valuable knowledge with us. During two workshops (in our lab and on-site) we discussed the inhibitors and his strategies for intervention. We also did participate in one of his full-day workshops. We briefly summarize our main findings in the following.

A key requirement for being able to control a creative session is awareness of the process and the group's verbal and implicit communication. The facilitator needs to make sure he stays on top of the process and in control of its proceeding by being able to direct the behavior of the participants in a sensitive way. Thereby, a particular challenging task is to maintain overview of the number of ideas, comments, their relations to each other and the direction a group is going to pursue. This is due to the fact that the facilitator needs to explore the ideas at the same time as they are created and distributed in the group. The most frequent way of intervention into the group's activity is verbal communication. The way such a communication is conducted however is crucial considering social inhibitors like evaluation apprehension. Therefore, facilitators also try influencing participants in a non-confronting implicit way such as the placement of inspirational artifacts in the ambience or by modifying materials. Another interesting aspect revealed by the professional facilitator was the need for reuse of the results of such sessions. As his processes are also paper-centric, a rather time-consuming part of his work is the analysis of produced artifacts and archiving ideas into digital repositories, which is a mandatory procedure for enabling reuse.

DESIGN

In the following, we will describe the procedure and rationale that led to the design of our system. As a first step, we extracted explicit tradeoff decisions from the findings of our analysis for the reality-based design of an interactive system. These tradeoff decisions can be seen as proposals as which parts of traditional practice should be preserved (reality) and where technology (power) might be used to improve the process.

Design Tradeoffs

We found that the traditional paper-based practices for ideation, externalization and sharing of ideas did not have any negative effects. In contrast, we believe that the use of technology such as pen tablets or interactive displays might even hamper the fluency of externalization and the ease of artifact handling in individual and shared territories. Therefore, we decided to strive for *preserving the material practice for ideation and sharing* activities (T1). Our analysis further revealed that participants had some complications with presenting and discussing small artifacts in the group which led to instances of free riding and fixation. Digital technology such as large displays might be used in a complementary way for presentation purposes. Hence, we decided to strive for *supporting improved visibility and accessibility* of artifacts (T2). Eventually, we

found that technology might be used most effectively for analyzing and visualizing the group's activities. An interactive visualization of individual contributions, the design process and history may *augment awareness and communication abilities of the facilitator* (T3).

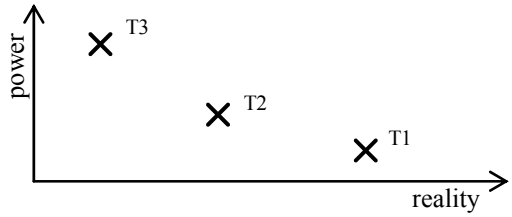

Figure 4. Design tradeoffs along a power vs. reality spectrum.

For our design process, we classified our tradeoff decisions along a power vs. reality spectrum [11] (see Figure 4). While T1 strives towards *preserving* reality as closely as possible, it does not add a lot of power (functionality) to the interface. T2 and T3 significantly deviate from reality by adding powerful digital features. Along the lines of the RBI framework, we think that reality should be given priority and power should be added when needed. Consequently, we iteratively designed the system workspace and interaction techniques from T1 to T3 along the spectrum towards power. This way, we could gradually increase the power of the interface by still ensuring that the digital functionality is complementary with our goal to augment traditional workflows.

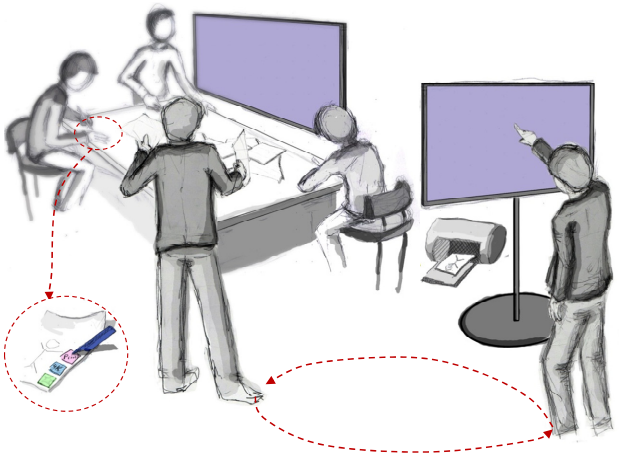

Figure 5. The IdeaVis workspace is based on digital pen & paper, a printer, a group display and a facilitator display.

Hybrid Workspace Design

With the aim of preserving material practice (T1), we decided to keep a traditional non-interactive table as main workspace and paper as work material (see Figure 5). This is in contrast to many other systems that use augmented paper directly on interactive displays. However, as a prerequisite for enabling additional functionalities, we employ digital pen & paper[1]. This technology allows users to work with regular paper that is augmented with a unique dot pattern. Multiple digital pens recognize strokes made on paper and send them to a computer via a wireless Bluetooth connection. We only provide one stroke color, for reducing identification to the participants. We also employ optional functionality available to the group via paper interface buttons. This hybrid workspace setting allows us to preserve traditional workflows and the quality of paper artifacts while at the same time enabling digital representations and functionality.

For supporting presentation and discussion in the group (T2), we added a large, very high-resolution display (65", 4096px x 2160px). It is mounted in close proximity to the table, just like a real pin-board would be in traditional settings. Furthermore, we provide an additional interactive display (55", 1920px x 1080px, multi-touch input) that is used to display interactive visualizations to the facilitator (T3). It is positioned away from the group as to not distract participants from their tasks. A facilitator can move freely between the group workspace and the visualization display. A laser printer is available to the group and the facilitator for printing and copying sketches either via a paper interface or the visualization interface.

Paper-based Interaction Techniques

Based on our workspace design, we designed paper-based interaction techniques that can be used by the group and by a facilitator. Therefore, the digital paper was augmented with three interactive regions for: 1) printing copies of a sketch, 2) displaying a sketch on the large display and 3) rating ideas (see Figure 6).

Using an interactive area on the paper labeled "print", a copy of the sketch is produced by the printer (see Figure 6, top). A visual feedback on the large group display shows the status of the printer queue to inform users if their actions were successful. We included the printing functionality for allowing the distribution of ideas to multiple other persons without the need to pass on the original. Thereby, it aims toward fostering comments via annotation and toward reducing evaluation apprehension issues. Modification or extension of ideas does no longer affect the original sketch, which might make participants more comfortable in commenting on ideas of others. However, when misused, this functionality might also lead to fixation as the need for re-drawing a sketch also supports re-interpretation. With this tradeoff, we enabled a way of forking ideas that is not possible with traditional material as the idea may then be edited or annotated by multiple designers at the same time. Overall, this functionality contributes to our second tradeoff.

By tapping the region labeled "highlight" on the paper, a digital representation of the sketch appears on the large group display and is zoomed to full-size after a couple of seconds

[1] www.anoto.com

(see Figure 6, center). The view of the sketch is live, which means that manipulations made on the paper are instantly transferred to the digital representation. While presenting, users may further use the pen to mark regions in the sketch to allow for deictic references. When tapping the area again, the view on the large display zooms out to show all highlighted sketches in a grid, ordered by the time they were send to the display. This way, designers and the facilitator can switch between an overview and a detailed view of artifacts by using the paper interface. By highlighting ideas, users implicitly select which ideas are visible for presentation and discussion, thereby limiting the number of artifacts in focus. This functionality also contributes to our goal in making artifacts more visible and accessible (T2). The large view of the sketch thereby facilitates an immersive shared representation that may increase group awareness and may also be helpful for facilitators to involve participants.

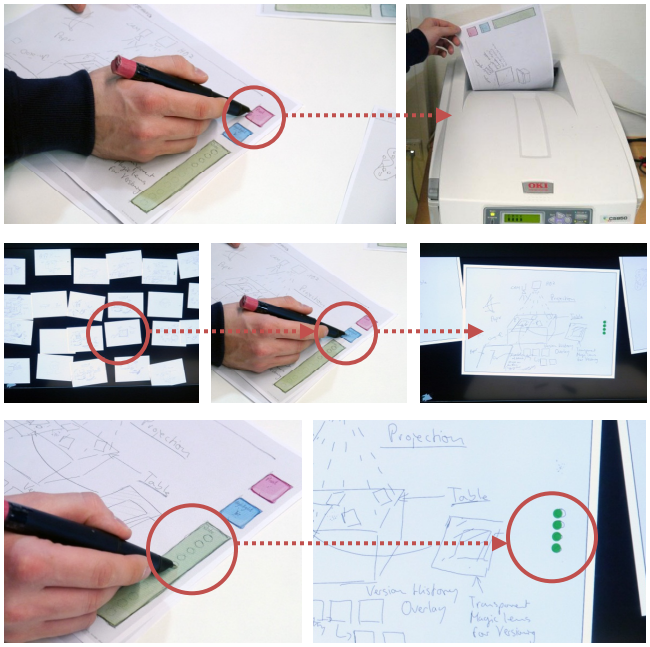

Figure 6. Interactive regions on the paper facilitate printing (top), presenting (center) and rating functionality (bottom).

Eventually, a third interactive region on the paper is dedicated for rating ideas. Users can draw small circles in these areas as to specify their support for this particular idea (see Figure 6, bottom). The number of circles drawn indicates a numerical rating. We use simple shape-based sketch recognition to count and visualize the rating of multiple users via a combined scale on the digital representations. Therefore, ideas may be rated individually, while the combined ratings are shown on the group display. Again, this functionality contributes to our goal of increasing group awareness (T2) and also moderates evaluation apprehension issues because the rating can be done privately on paper in a protected workspace.

Design Activity Visualization

Some of the paper-based interaction techniques already contribute to the goal of improving awareness and accessibility. From our analysis however, we learned that the facilitator may benefit from an overview of the process, the ideas created and the re-interpretations made. Therefore, we developed a mechanism that utilizes the stroke data retrieved from the digital pens to keep track of all changes made on the paper over time and their relation to their authors or annotators. Based on the identification data of different pens and different paper sheets, we were able to track a trajectory (time-ordered set of states within a dynamical system) of idea progression and forking as well as original authors or modifiers and annotators.

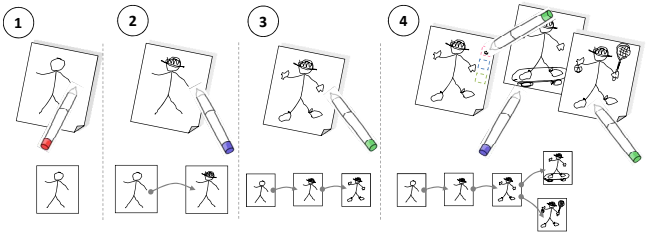

Figure 7. Digital stroke data is analyzed for creating trajectories of ideas, manipulations and their annotators.

Figure 7 describes this procedure in detail. Once a sketch is produced on paper, a digital version is recorded in the system (Figure 7, 1). It stores the pen id and the paper id. When a different pen is used on the same sheet of paper, a second version is linked to this item (Figure 7, 2). This continues for each unique pen that is used on that paper, building a chain of versions (Figure 7, 3). Note that this chain is only known to the system, as users are not able to distinguish between different pens by looking at the paper only (except possibly in the case of handwriting). In the case of a print command, the system forks the trajectory, creating a tree-like versioning history (Figure 7, 4). For the printout and the original, the procedure may continue recursively from the second step (Figure 7, 2).

We used the data provided by the versioning trajectory for the design of an interactive visualization for the facilitator display. Because extensive sketching sessions result in a large number of ideas and very deep trajectories, we decided that a focus & context visualization technique would be most adequate. We found a suitable concept in the hyperbolic tree visualization [14], which supports the interactive exploration of large hierarchies within a circular fisheye view. We adapted the concept for our purpose, using sketches as nodes (see Figure 8). Sketches that are produced during the session are dynamically added to the tree in clockwise direction around a central node (see Figure 8, 1). The central node serves as a hub, displaying statistical information such as the number of unique ideas, the number of pens and a link counter (which is a measure of the degree of re-interpretation). Once links are created in the trajectory, child nodes are dynamically added to the tree

(see Figure 8, 2) which makes it grow over time. We use color coding around the border of the sketches to indicate whether a sketch is an original, an annotation or a copy (see Figure 8, 3). Sketches that are currently being manipulated by the participants of the session are highlighted with a circular glow that fades over time (see Figure 8, 4). This awareness mechanism allows a facilitator to detect the current focus of the group's activity. Overall, the visualization conveys a history of the session (clockwise arrangement), the number of ideas (size of the tree), the degree of re-interpretation (depth of the tree), fixation (uneven distribution of nodes) and the activity of the group (highlighting) at a glance. Thus, it conveys content-based information to the facilitator that goes well beyond a timeline session history and that can be used for analyzing the session.

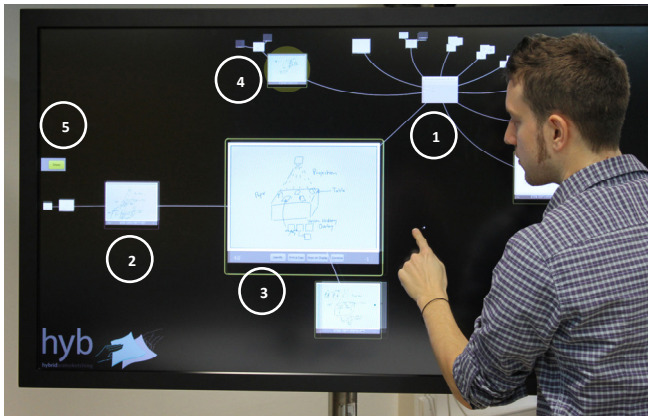

Figure 8. An interactive hyperbolic tree visualization conveys the recorded data for exploration by the session facilitator.

The facilitator can interact with the visualization with touch gestures for dragging and zooming. By dragging a part of the tree to the center of the display, the respective nodes are enlarged for a more detailed view. At the same time, nodes that are situated at the opposite end of the central node are scaled down, thereby keeping the context in reach of the facilitator. Zooming gestures can be used to focus on a specific node in detail (tap gesture) or to examine a region of the tree (pinching gesture). Each node again is a live view of the paper sketch, instantly displaying the stream of strokes from all digital pens and the rating scale if applicable. Further, each sketch in the tree has a toolbox of buttons (see Figure 8, 3 and Figure 9) which enables additional functionalities for the facilitator. For being able to identify authors and annotators of ideas, we attached colored labels to each pen that correspond to the identification data of the pens in the system. Hence, our system is able to reveal identification data to the facilitator on demand. By pressing the "Identify" button, a dropdown item shows all colors (i.e. authors) that contributed to the particular sketch in the order of occurrence (see Figure 9). Pressing the colored buttons highlights strokes within the sketch with that color for visualizing which part of the sketch was created by that author. This way, the facilitator has awareness of individual contributions and may use this knowledge for directing group activities (e.g. stimulate passive participants). He is also able to distinguish between the originator of an idea and annotators, which would be impossible by looking at the paper sheets only.

Figure 9. Buttons beneath each sketch allow the facilitator to identify authors, to print a copy, to transfer the sketch to the group display and to combine different sketches.

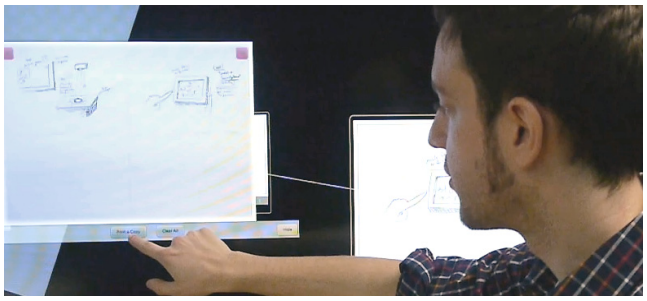

Figure 10: A clipboard is used to combine sketches. This view can also be printed on paper for distribution to the group.

The buttons "Print a Copy" and "Show on Display" are equivalent to the functionality of the paper interface for printing and presenting sketches. The facilitator may use this functionality for manipulating the group's activity either by displaying a specific sketch to the group for discussion or by printing a selection of sketches for systematic placement in the group. The facilitator may also use his own pen to write questions on the printout to further emphasize specific aspects worth exploring. Eventually, a "Combine" button allows for merging different sketches from the tree. By pressing the button, the sketch is sent to a clipboard that is displayed within a drawer on the left side of the interface (see Figure 8, 5 and Figure 10). Sketches sent to the clipboard are scaled down and arranged on a single paper sheet that can be printed from within the clipboard view. By enabling the facilitator to collect related ideas, he may control the group's activity toward convergence.

USER STUDY

We conducted a small user study to investigate how the provided tools might affect the work of designers and facilitators as well as the characteristics of the original technique. Our goal was not to measure the effect of the system on a measure of creativity or the productivity of brainsketching sessions. While this is a reasonable research question, as a first evaluation, we rather sought to investigate if our tradeoff decisions were adequate and how they may be improved. Therefore, we performed a controlled lab study with novice designers and professional creative facilitators.

Study Design

We invited two groups of graduate students in design (N=7, 6 female, avg. age 27 years, study program "creative direction") and two professional facilitators from the innovation lab of a large German automotive company (male, avg. age 41.5 years, avg. experience 4 years). Over two days, we conducted four brainsketching sessions in our lab. Two sessions were practiced in a traditional way using pen & paper and a pin-board (condition one), and two sessions were conducted using the IdeaVis system (condition two). This way, we were in control of the tool (independent variable) and may observe its effects on the method and the facilitator (depended variables, see Table 1). For being able to compare our system with traditional practice, we applied a within-subject design using the same group of students for both conditions. On both days, condition one was conducted before condition two. Each session lasted between 1 and 1.5 hours with breaks in between to minimize fatigue. We modified the setup for the traditional sessions by replacing the group display with a pin-board and by replacing the supplied paper with non-interactive, blank sheets. However, participants worked with the digital pens in both conditions in order to minimize the effects other tools may have. Based on recommendations by the creative facilitators, we provided a standing-height table as primary work surface. The use of IdeaVis involves leaving the group occasionally, thereby creating a tradeoff between the use of verbal conversations or non-verbal communication via the system. To investigate this, we employed one facilitator on the first day and a team of two facilitators on the second day. Figure 11 shows condition two (IdeaVis) on the first day (top) and on the second day (bottom).

Figure 11. IdeaVis was used most effectively with a second facilitator who analyzed live design activity in the background.

Participants were introduced to the brainsketching technique with a warming-up activity. Similarly, all participants were introduced to the second condition with a demonstration and exercise of the paper-based interaction techniques. The facilitators were also introduced to the visualization and were given a handout with a summary of available functionality. The participants were then asked to work on design problems. The tasks were defined independently by the facilitators. Objective one was: "How to get people to return their coffee cup after meetings?" and objective two was: "How to get people in meetings to use their coffee cup more than once?". We used the same objectives within both groups, but alternated their order.

Method of Analysis

We collected material in the form of questionnaires, video recordings, observation notes and still photos. We also conducted a focus group with all participants at the end of each day. Two types of questionnaires were handed out before and after each session. We taped all sessions using a digital video camera with a wide angle that allowed recording both the group's activity and the work of the facilitator (see Figure 11). The use of functionalities like printing, highlighting, rating, identifying, and combining was logged to a text file. We analyzed all material based on our tradeoff decisions and the methodology of qualitative content analysis. Therefore, we collected evidence for each of our tradeoff decisions by examining the frequency of use (logging data), problems occurring with the use of the functionality (observation notes and focus group), rating scores of functionality (questionnaires, 7 point Likert scale, 1=strongly agree, 7=strongly disagree), by scanning and extracting video sequences and by partly transcribing verbal communication of the focus group.

Results and Discussion

We may evaluate our first tradeoff decision (T1) by looking at the effects the provided tools had on the design method and their impact on the work of the facilitator. As we employed digital pens in both conditions, we may refer to the feedback of participants and the facilitators regarding a comparison to traditional practice. Overall, during all sessions participants had no problems in externalizing their ideas with digital pen & paper material and the use of the table (M=1.86, SD= 1.01). Not surprisingly, we could observe similar interactions as with regular paper, like skipping, grabbing and turning as means for transferring artifacts between individual and shared workspaces. We also frequently observed communication accompanied with deictic references. The facilitators did not see any negative impact of their work practices with the use of the digital pens. Therefore, we may conclude that the digital pen & paper material did not affect traditional workflows in a negative way.

By employing a group display and paper-based interaction techniques, we significantly departed from what is possible with traditional media (T2). All our subjects found the functionality of the paper interface useful (M=2.0, SD=1.73). They also agreed that the functions were easy to use (M=2.43, SD=1.61) and that the feedback provided by the

system was sufficient (M=1.43, SD=1.13). The rating function was not as easy to use as the other functions (M=3.29, SD=2.14). It was recommended to use a simpler mechanism without gesture recognition. The printing function was used by five participants (9 out of 52 sketches were duplicated). They all strongly agreed that it is a helpful functionality (N=5, M=1.0, SD=0) for distributing ideas. Printing was however used mostly by the facilitators. Our questionnaire revealed that evaluation apprehension was no issue within the groups (fear of criticizing: M=6.86, SD=0.38). We think that this fact and the availability of the group display limited the use of the printing function. During the first day, the facilitator incorporated printing in his work practices. Asked for his reasons in doing so, he said: *"So, I just wanted to try this function because it promotes branches of the design content. Then, two persons can work at the same time into two different directions"*. This statement supports the usefulness of this functionality for branching ideas. On both days, the copies were used as intended, for adding annotations rather than for re-interpretations. The presentation function was consistently considered helpful for showing ideas to the group (M=2, SD=1.33). During discussion however, the display was used mostly exclusively and participants almost forgot about the physical paper. Our facilitators stated that the immersive size and quality of the display had a strong influence on attention and that it is a powerful tool for controlling the focus of the group. When we asked participants to compare their experiences with IdeaVis with the traditional sessions, all of them agreed that it did enhance the original procedure. However, while the group stated that the use of the display is certainly a benefit for them, they particularly liked that they did not have to leave their individual workspaces for using the features on the paper, hence preserving the social situation. The facilitators found most value in the additional options the paper has for controlling the group without having to use the facilitator display.

Eventually, with our third tradeoff we provided an interactive visualization for facilitators (T3). In comparison with the other tradeoffs, this is certainly the most powerful, providing tools that are not required by the method per se. Therefore, the facilitators had to adapt their traditional strategies in order to make use of the visualization. Both facilitators stated that the focus & context nature of the visualization is valuable for having all states of the process visible and that the trajectory is indeed an adequate way of capturing and analyzing sketching activities in rich detail. They especially emphasized the value it has for improving their daily work not only during the sessions but also after the sessions. When asked for the most unique benefits of the visualization, the facilitators stated that fixations are instantly recognizable by especially deep trajectories in the tree. We found that the use of a co-facilitator who is dedicated to analyzing the design activity in the background (see Figure 9, bottom) is most effective. This strategy was instantly favored by the facilitators on the second day as they have also similar practices when conducting creativity workshops with multiple groups. By scanning the tree for modifications indicated by the fading glow, the co-facilitator did only have to communicate with the group facilitator directly (mostly through gestures and short comments) and only indirectly with the group by using the system or printed artifacts. He also made frequent use of the identification, printing and highlighting functionality within the toolbox of the sketches than our single facilitator did on the first day. When asked, he did state that he used these features mostly for finding interesting ideas and for enforcing a re-interpretation or clarification of these sketches. The zooming functionality proved to be essential because the facilitators made frequent use of it for examining sketches in detail. The facilitators highlighted that the benefit of the visualization may further increase with the number of participants. Both facilitators agreed that the visualization opens up a different, more content-focused view on the creative process than is possible with observing the session in a traditional way. Asked for their value in cooperation, the group facilitator stated that "*[the co-facilitator] contributes to the problem-solving process and he can ask specific questions to the facilitator or to the group. This doesn't make the session more creative but more productive, as [the co-facilitator] can ask the 'better' questions"*. This statement confirms our assumption that the visualization is used most effectively for directing the group toward convergence. Overall, our facilitators stated that IdeaVis can indeed provide a benefit for better understanding group dynamics during the session and for improving awareness and communication abilities. However, both facilitators said that the system should be extended with a manual clustering functionality to allow for collecting good ideas as a complement to the existing automatically generated visualization. Being able to combine sketches via the clipboard is a step toward this direction, but may be further improved with more flexibility. Further suggestions were the use of a tablet device for the facilitator display as this may reduce division of attention and the need for leaving the group.

CONCLUSION

In this paper we presented IdeaVis, a novel approach for supporting paper-based sketching sessions. Based on a literature review, observations and the needs of a professional creative facilitator, we identified tradeoffs that we utilized for designing a subtle way of integrating digital functionality into traditional workflows. Using digital pen & paper and high resolution displays, we developed a hybrid workspace that augments traditional practices. A user study confirmed that the functionality of IdeaVis is considered useful by both novice designers and professional creative facilitators. Based on the feedback we received from our study participants, we believe that the system has potential to make sketching sessions more focused and hence more productive. However, a longitudinal study involving a larger user population and possibly quantitative measures will be necessary to investigate to what extent the

functionality contributes to re-interpretation and exploration of design ideas. Our system introduced the novel concept of visualizing design activity that can be further extended and improved. While a tree-like visualization was employed, there are certainly other ways of visualizing design activity that can be used by facilitators for analyzing and controlling similar creative group activities. In particular, we investigate the use spatial grouping techniques [4] for supporting such activities of reflection. We may conclude that hybrid workspace designs can be used to preserve and extend traditional workflows. Nevertheless, in combination with design activity visualizations they can moreover provide advanced awareness and control over typical inhibitors of creative group work.

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