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Designing Reality-Based Interfaces for Creative Group Work

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ABSTRACT

Using affinity diagramming as an example, we investigate reality-based interfaces for supporting creative group work. Based on an observational study grounded in the reality-based interaction framework, we identified power vs. reality tradeoffs that can be addressed to find a close fit to embodied practice. Using this knowledge, we designed and implemented a digital workspace for supporting affinity diagramming. Its hybrid interaction techniques combine digital pen & paper with an interactive table and tangible tokens. An additional vertical display is used to support reflection-in-action and for enhancing discussion and coordination. A preliminary user study confirmed the applicability of our tradeoffs and the general acceptance of the tool design.

Author Keywords

Creative group work, affinity diagramming, reality-based interaction, digital pen & paper, hybrid interactive surfaces

ACM Classification Keywords

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

General Terms

Design, documentation, experimentation, theory

INTRODUCTION

During early phases of design processes, designers often closely collaborate on design problems and design solutions. Especially during idea generation and evaluation activities, cooperation can lead to more creative ideas and better solutions [22]. The most effective cooperation between designers frequently takes place in traditional co-located sessions in combination with structured methods and techniques that moderate the influences of social factors [7]. The use of technology in such group sessions is often considered harmful since using desktop-based digital tools would isolate participants, leading to a breakdown of communication that is vital for a shared understanding in the group [18,19]. Rigid interaction modalities may further impose limitations on crucial characteristics of design practice, like the workflow of design methods, coordination and communication as well as embodiment of thought. As long as digital tools do not consider and actively support these aspects, they will hardly be adopted for use in practice.

As a result, designers often use traditional media for group sessions. 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]. Thereby, physical artifacts serve as boundary objects and as a collective memory for facilitating discussion. In design studio environments, the physical space in the room itself is an important tool that allows organizing information in an informal and fluent way [20]. Design sketches for example can easily be shared on large whiteboards or spread out on tables for comparison and discussion with other designers. While these aspects facilitate efficient cooperation in face-to-face sessions, they also lead to challenges concerning the documentation and sharing of results in digital repositories, which is often desired during the course of a design project. Due to the dynamic nature of creative work, organizing and archiving individual contributions in a formal structure is an awkward task that often fails and therefore impedes the reuse of design knowledge in later phases of the design process. Furthermore, by solely relying on physical material, designers cannot benefit from the power of digital tools that could be used to augment ideation and synthesis by providing additional information or by enabling reuse, sharing or analytical functionalities. Both strength and limitations of embodied practice point to the need for an integration of computational functionality with physical tools for better supporting creative group work.

It is only recently that ubiquitous computing technologies which blend in with the physical environment promise a better integration of technology in co-located collaborative work. Interactive surfaces, like tabletops or wall-size displays, closely resemble real-world work surfaces. Multi-touch interfaces can provide multi-user workspaces, allow for equal participation of users and thus may improve group awareness compared to desktop computing [3]. Nonetheless, they may also stimulate engaging and playful explorations by simulating the physicality of the real-world. Tangible user interfaces (TUIs) allow for combining digital information with the affordances and qualities of physical artifacts. They may also be actively used to democratize interactions [9]. Hybrid interactive surfaces [14] combine direct-manipulative interfaces like multi-touch tabletops with TUIs and therefore provide a large design space that should be further explored in the context of creative group work.

Theoretical frameworks such as Reality-based Interaction (RBI) provide guidance on how to utilize this huge design space for designing user interfaces that build upon the knowledge and experiences of people in the "real world" [10,11]. RBI is based on the assumptions that people's interactions in the real world are highly practiced and robust and thus require little effort to learn and perform. In the design of reality-based interfaces, designers and researchers therefore should consider a "power vs. reality tradeoff", with the goal "to give up reality only explicitly and only in return for increasing power" [10]. A wisely chosen balance between the power of the interface and its level of reality enables the digital tool to go beyond the possibilities of the real world. We argue that by investigating embodied practice in creative group work using RBI, we can identify critical tradeoffs between reality and computational power. By carefully considering these tradeoffs in the design of digital tools, we may overcome the described limitations of creative practice and provide additional benefits through computational power. Consequently, we seek to answer following research question:

RQ: Can we design reality-based tools that preserve the original workflow and embodied practice of creative group work but also enable additional functionality?

To answer this question we chose to study a specific collaborative design method in order to identify crucial characteristics of embodied practice with a real-world example. Using this data, we seek to identify tradeoffs that allow augmenting practice without changing crucial characteristics of the original workflow. Based on this, we may then design and implement reality-based interfaces to examine the effects of these tradeoffs.

RELATED WORK

Our work extends related research in computing environments for co-located creative group work. A range of researchers have presented promising approaches for supporting design sessions with tangible user interfaces and interactive surfaces.

An influential tangible approach was introduced with *The Designer's Outpost* [15]. This digital tool introduced paper-based interaction concepts in the context of collaborative web site design. It combines physical sticky notes with an interactive whiteboard system. By using overhead image capture, notes can be combined with digital ink annotations for creating hybrid website diagrams. The system thereby bridges physical and digital representations to support the documentation and sharing of results. Yet, the system lacks efficient multi-user support and is only suitable for a limited number of physical artifacts. *Pictionaire* [6] also uses overhead image capture and projection to combine physical artifacts with digital annotations on a hybrid tabletop system. The system thereby supports the sharing and discussion of digital and physical design artifacts within idea-generation activities. It also provides digital containers for creating storyboards from captured or retrieved images.

Researchers have also shown that interactive surfaces and multi-display environments can be used to support creative group work. i-LAND [18] combines interactive surfaces, like tables, walls and mobile devices, for supporting fluent creative collaboration and for easing the transfer of information across devices. But, it focuses on the design of an adequate technical infrastructure instead of addressing specific tasks or support for established workflows. *BrainStorm* [8] combines multiple pen-operated displays to support creative problem solving processes. Digital notes can be created on an interactive table and transferred to a wall projection for discussion and clustering. Thereby, it provides stylus-based interaction techniques for creating, sharing and clustering of digital notes. Though, it does not add supplementary functionalities to significantly augment practice and supports only dyadic groups. *The Designer's Environment* [5] supports the KJ creativity method with multimodal interaction techniques for grouping and linking digital notes on a tabletop system. Handwritten digital notes are sent to the table from multiple tablet PCs. Text recognition is used on the tablets for retrieving images from the web according to the content of notes. The system however primarily focuses on novel multimodal interaction techniques for grouping digital notes rather than workflow support or support for tangible media. *TeamStorm* [4] combines multiple Tablet PCs with an interactive whiteboard interface for collaborative sketching sessions. Sketches can be transferred from mobile devices to the whiteboard for coordinating discussion in the group and for enhancing reflection activities. The system shows how technology can be effectively used to support social interactions across digital artifacts. However, like many of the presented systems, it replaces physical practice, thereby requiring the exclusive use of digital modalities.

Many of the described approaches share our goal to integrate technology into physical design practice. Some systems may also be partly classified as reality-based interfaces. However, many design decisions were made implicitly, without stating the tradeoffs to physical practice, existing workflows or their impact on the embodiment of actions. Consequently, we seek to make our tradeoffs between physical practice and digital tool support more explicit than other researchers.

ANALYSIS

In the following we will describe a detailed analysis of embodied practice using a structured observation of a specific real-world example. The knowledge gained from this analysis is to be used for identifying potential tradeoffs.

Theoretical Framework

The RBI framework [11] provides the theoretical foundation for our approach because we consider its themes adequate for identifying crucial characteristics of embodied design practice. In an initial description of RBI, Jacob et al. provide general guidance on how to deal with the tradeoff between power and reality [10]. In a following paper [11], they further refine their definition of reality and distinguish between four themes of reality-based interaction that should be considered when designing interfaces, namely: naïve

Figure 1. Our study focused on the use of workspaces (a), interaction with artifacts (b, c) and social interactions (d,e).

physics (NP), body awareness and skills (BAS), environment awareness and skills (EAS), as well as social awareness and skills (SAS). NP considers people's knowledge about the physical world, like gravity, friction and relative scale. These characteristics may be simulated by using physical metaphors such as multi-touch manipulations or TUIs. BAS describes people's knowledge and experiences of working and thinking with their bodies. Interactive systems may therefore also consider whole-body interaction as interaction modality. EAS includes the navigation and manipulation of the physical environment as well as the orientation and spatial understanding in the environment. These aspects may be considered when designing digital work surfaces or objects. SAS deals with people's interactions and communication amongst each other, including group dynamics in collaborative work and the exchange of artifacts among group members. TUIs are an example for interfaces that may augment this theme.

Technique Selection

Creative professionals hardly work in group situations without a formal structure or workflow [7]. A wide variety of methods and techniques provide control over social factors and group coordination. Hence, we decided to focus our investigation on one representative example for creative group work that includes a methodic workflow. Affinity Diagramming [1] is a collaborative design method applied early in the design process for analyzing a design problem or to create first design solutions. It is typically practiced with pen & paper and a shared surface such as a whiteboard or a large wall. Beyer & Holtzblatt [1] explicitly recommend traditional media for practicing affinity diagramming. The technique consists of three main phases: 1) generating (participants individually create content on sticky notes), 2) sharing (participants present and collect notes), and 3) structuring (participants arrange notes into meaningful categories). These basic phases (ideation, sharing and evaluation) can be considered typical for a range of collaborative design methods that have the goal to achieve a shared understanding of design problems or design solutions [7]. While other methods may employ other contents and design artifacts, affinity diagramming is explicitly limited to words, sketches or short sentences on small sticky notes to stimulate diversity in ideation phases. During convergent phases, shared understanding is further promoted by the collaborative task to make sense out of a large number of artifacts. Due to the high frequency of actions that are enforced by the use of small artifacts, this technique is especially suited for a quantitative analysis.

Observation

By analyzing individual interactions with the environment (EAS), communication with group members (SAS), embodied interactions (BAS) and the use of physical artifacts (NP), we strive to identify aspects of affinity diagramming practice that should be preserved and issues that may benefit from computational power. Therefore, we observed three groups of students (4-6 each, N=15) practicing affinity diagramming within a hands-on session in context of an interaction design course. The work environment was based on a horizontal (table) and a vertical (whiteboard) work surface (see Fig. 1,a). We further supplied colored sticky notes and pens. After an introduction to the technique and a design problem, the students carried out the design technique independently. The group sessions were videotaped and lasted between 1.5 and 2 hours. In addition, each group session was observed by a researcher who made notes of the group's activities. Based on the procedures of interaction analysis [13] and qualitative content analysis, separate categories within the four themes of RBI were inductively developed for coding the videos. Doing so, multiple iterations were conducted before the code scheme was considered to be saturated and sufficiently described the data set. Two sub-sets of video-data (one part covering the two phases of generating and presenting notes and one part covering the phase of sorting notes on the whiteboard) were coded by two independent researchers. In order to do so, the video was separated into chunks and both coders were then asked to code the chunks into categories. Coding was not exclusive to the categories, which means that one chunk could also be coded into multiple categories. An inter-coder reliability analysis revealed a Cohen's Kappa of 0.86, which was considered to be satisfactory. The whole data-set was then coded by one researcher.

Overall, three categories describing participants' interactions with the environment (EAS) were derived from the most frequent coded events across the design sessions. We distinguished between participants focusing their attention on the table, the whiteboard as well as on other individuals. The frequency of these actions is given in Figure 2 for each of the three categories. The values describe the percentage of the time the video was coded into the categories for each of the three phases. In the first phase, participants primarily worked in individual workspaces on the table (86%, see Fig. 1,b). In the third phase, individual attention was mainly distributed between other participants (18%) and the whiteboard (74%). Phase two was characterized by transitions between these workspaces. All groups used the whiteboard as a shared workspace during convergent activities. However, participants made use of their individual workspaces throughout the sessions. We also observed rapid changes of attention between individual and shared workspace as well as between different participants during the third phase. Through a qualitative analysis, we found that when engaging in actions during convergent activities, the view on the vertical surface was frequently blocked by members of the group, thereby limiting access and visibility to the other participants (see Fig. 1,d).

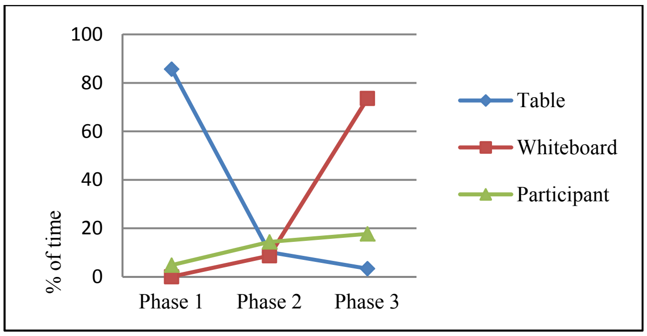

Figure 2. Coding results for EAS

Participants' social interactions (SAS) were investigated based on the kind of communication that they engaged in with other members. This included discussion, presentation as well as silence. While participants mostly worked quietly in the first phase (96%), the second phase was characterized by the presentation of artifacts (16%) and short discussions (5%). The third phase was dominated by extensive discussions (22%). Thereby, we observed alternations between detailed discussion of specific artifacts (see Fig. 1, e) and group coordination that required an overview over all artifacts.

Concerning physical and bodily interactions (NP and BAS), four categories were identified that describe these key interactions within the design sessions (see Fig. 3). In the first phase, each participant spent on average 60% of the time creating content and 56% on sorting notes within an individual workspace on the table (see Fig. 1, b). Based on overlapping data within these categories, we could identify that creation of content is tightly coupled with sorting actions in a personal workspace. Our qualitative analysis revealed that participants were utilizing the personal workspace for preparing contents for presentation or to search for inspiration by reflecting on created contents. Nevertheless, we could also observe that the pre-sorting behavior led to physical restrictions during the transfer of artifacts between workspaces due to the physical distance between these surfaces. For example, participants used mobile piles in their hands (see Fig. 1, c) to keep their artifacts in order when presenting (36%) or to collect notes during discussion (7%). Both the second phase and the third phase were accompanied with sorting actions on the whiteboard (~13%). Due to the small size of artifacts and their spatial distribution on the whiteboard, we could observe mutual blocking when participants were engaging in parallel actions at the partly very crowded whiteboard (see Fig. 1, d). We also observed that participants frequently used their bodies (e.g. fingers and arms) for deictic gestures to emphasize the focus of discussion to other participants (see Fig. 1, e). Overall, sorting notes into categories required mutual understanding and consensus in the group.

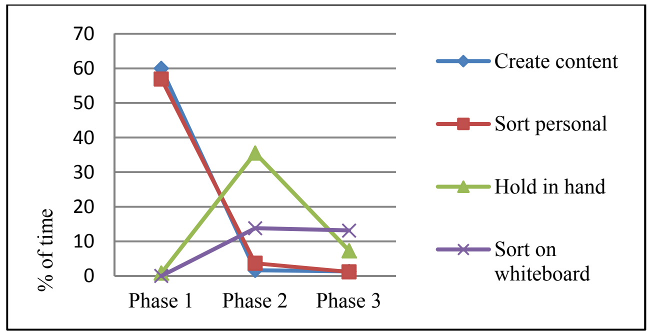

Figure 3. Coding results for NP and BAS

Power vs. Reality Tradeoffs

Based on the results of our study we examined potential power vs. reality tradeoffs. The goal of this investigation was to identify characteristics that should be preserved because they are considered crucial to the effectiveness and efficiency of the design method (Reality). At the same time, we thought about potential divergences from reality that may allow augmenting typical tasks (Power).

Physical Workspace vs. Digital Workspace

We believe that the design of the physical work environment has implications for group awareness and social factors like production blocking (EAS). Work surfaces were appropriated due to their differences in accessibility of artifacts and available display space. This finding is supported by studies from Vyas et al. [20,21], that describe the appropriation of physical surfaces in professional design studios. The authors report that horizontal surfaces mainly serve as a space for *action*, while vertical surfaces are useful for *reflection* during convergent activities. Physical blocking is likelier to occur on vertical surfaces (see Fig. 1, d), while overview on multiple artifacts is limited on horizontal surfaces. Thus, we argue that both types of surfaces should be preserved, but may be enhanced through computational power to increase visibility and accessibility.

Within convergent phases, we observed alternations between manipulations and reflection and between detailed discussions of artifacts and coordination activities that required an overview on all created artifacts (SAS). These findings are in line with reflective practice as described by Schön [17]. Though, we also found that this behavior may lead to coordination and communication issues when dealing with a large number of artifacts during discussion. At some points, participants had problems following discussion due to rapid shifts of attention or because some artifacts on the shared work surface were blocked by other participants. Therefore, we argue that this activity should be actively supported to aid participants to "think what they are doing while they are doing it" [17].

From our analysis we also discovered that individual workspaces are essential for preserving the workflow of the design technique because they moderate social factors like evaluation apprehension by providing a semi-private retreat from the group. This conclusion is in line with findings reported by Warr & O'Neill [22]. Other social factors like production blocking and free riding are partly addressed by the workflow of the design technique itself (SAS). Conversely, we discovered issues with the transfer of artifacts between workspaces throughout the sessions. Consequently, we argue that individual workspaces should be preserved, while the transfer could be improved with computational functionality.

A possible solution to these tradeoffs could be a digital workspace that replicates the physical properties for action and reflection activities, but at the same time provides additional features to enhance equal access and group awareness, thereby fostering shared understanding in the group.

Physical Artifacts vs. Digital Artifacts

We observed that physical artifacts are especially useful during individual *divergent* activities, where a large number of different artifacts are created in rapid cycles. Participants used paper notes efficiently within tightly coupled alternations between individual creation and reflection (NP). This is in line with results from a study reported by Cook & Bailey [2] on the use of paper in professional design practice. The authors conclude that paper is highly appreciated due to its unique physical affordances that support both fluent access and flexible handling. They also emphasize the usefulness of paper in face-to-face collaborations. However, we found issues with the transfer of physical artifacts between workspaces and their visibility and accessibility during *convergent* phases (BAS). This is partly due to the small size of the artifacts and their spatial distribution. Nevertheless, this may influence group awareness and coordination.

A possible solution to these tradeoffs could be to employ hybrid artifacts that have both a physical and digital representation. The physical representation could be used within individual divergent activities, while the digital representation may offer improved visibility (e.g. magnification) and improved accessibility (e.g. parallel access). Digital representations would also allow for more advanced functionalities, like duplication, semi-automatic grouping and associations with additional or analytic information that may improve ideation or reflection activities. Still, the transformation between these representations needs to be smooth to minimize the costs of this transition. At the same time, digital representations should mimic the affordances of physical artifacts as closely as possible to allow for embodied interactions like deictic gestures that are important forms of expression.

Tradeoff Decisions

We summarize our analysis with following specific tradeoff decisions: T1: preserve the physical workspace setting; T2: preserve individual ideation and reflection with physical artifacts; T3: support the handling of digital artifacts during convergent activities; T4: augment collaborative actions with more equal access and better visibility of artifacts; and T5: augment reflection activities for improving coordination and group awareness.

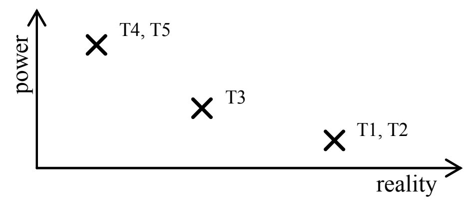

Figure 4. Tradeoffs along the power vs. reality continuum

Figure 4 visualizes these tradeoffs along the power vs. reality spectrum [10]. While T1 and T2 strive to *preserve* reality as closely as possible, they hardly add power to the interface. Nonetheless, these are necessary to ensure our goal to preserve the original workflow of the design technique. T3 departs from closely imitating reality in order to *support* convergent activities through the use of digital artifacts. However, the goal should be to transfer important characteristics of physical artifacts and sacrifice less important characteristics for computational power. T4 and T5 add digital features that are not possible in the real world. They significantly depart from reality by offering "super powers" [11]. The challenge is to design these tradeoffs in a way that does not negatively influence T1 and T2. Therefore, T1 and T2 have priority and T4 and T5 should be designed in a way that *augments* rather than changes.

DESIGN

We translated our tradeoffs into specific designs in order to test whether they can be successfully implemented by using ubiquitous computing technologies. Because T1 and T2 were given priority, we decided to design an adequate workspace first, before designing interaction techniques for the other tradeoffs in a second step. Doing so, we wanted to make sure that T3 to T5 do not conflict with the basic workflow and that the interaction techniques complement the workspace setting.

Workspace Design

With the aim of preserving the physical workspace setting (T1), we decided to keep the basic layout of one horizontal and one vertical work surface. But, these are to be replicated by using interactive displays. This design decision will allow using dynamic visualizations of digital representations of artifacts, which is the key to multiple other tradeoffs (T3,T4,T5). Figure 5 shows the final workspace design, which is based on a large interactive table for collaboratively interacting with artifacts and a very high-resolution wall display. The table is to be used for interacting with digital

Figure 5. Workspace design: shared action space (a), reflection space (b), personal spaces (c) and transfer spaces (d).

artifacts (*shared action space,* see Fig. 5, a), while the vertical display is to be used for reflection (*shared reflection space,* see Fig. 5, b). Thereby, we seek to preserve the benefits of both types of surfaces, but concentrate manipulations on a horizontal surface that is equally accessible to all participants. Because the vertical display cannot be blocked, it improves the visibility of artifacts. However, this decision either requires a transfer of artifacts from the *action space* to the *reflection space* or a virtual workspace across these displays. Because we want to minimize the effort of transferring artifacts, we decided for the latter by implementing the possibility of providing different "views" onto a virtual workspace that spans across the displays. Thereby, the table only displays a magnified region (*detail view*) of the whole workspace, which is shown on the vertical display (context view, see Fig. 5, center). Consequently, the same digital representation of a note is available on both displays. The workspace can be navigated via panning gestures on the table. A *focus box* on the vertical display visualizes the view that is currently displayed on the table (see Fig. 5, b). The coupled vertical display can also be used for dynamic views on selected artifacts during phases of discussion (see Fig. 5, right).

Since we seek to preserve individual work with physical artifacts (T2), we decided to employ digital pen & paper for supporting individual ideation and reflection activities. Therefore, the table offers individual workspaces on its non-interactive rim (*personal spaces,* see Fig. 5, c). By providing small paper notes and multiple digital pens we can preserve the ability for individuals to create and reflect upon their contributions in a natural way. At the same time, we gain the ability to integrate further computational power for adding power to the interface. For additional functionalities (T4,T5), we later also added optional personalized interactive areas at the corners of the table (*transfer spaces,* see Fig. 5, d). These interactive zones can be accessed on demand by pressing buttons in each corner of the table. They provide the possibility for personalized interactions within the shared workspace.

Interaction Techniques

Based on our workspace design, we designed hybrid interaction techniques to support the basic workflow of affinity diagramming through *copying*, *clustering*, *piling*, and *collecting* (T1,T2,T3). Additional functionalities that augment physical practice were integrated with interaction techniques for *highlighting*, *focusing*, *searching*, and *image retrieval* (T4,T5).

Copying

Within the first phase of the technique, participants work quietly in their individual workspaces. However, when presenting their notes in the second phase, they need to transfer their contents into the shared workspace. Since our shared workspace is digital, a conversion between the physical and a digital representation is necessary. To simplify this transition physical notes can be copied to the shared workspace by placing them on the interactive table (see Fig. 2, center). A digital representation of the physical note appears within the virtual workspace (on both displays), while the physical copy is kept in the personal workspace. Users may manipulate their notes later on by writing or crossing out words on the physical note. These manipulations are synchronized with the digital copy. When placing a note onto the table that was already copied into the workspace, it is not duplicated but moved to this new location instead. Overall, this technique allows the sharing of artifacts with minimized transfer costs while still preserving the ability to reflect upon all individual contents in the personal workspace throughout the session. It also enables rapid switching between the personal and the shared workspace.

Clustering and Piling

During convergent activities, notes can be discussed and organized into meaningful arrangements. Once copied into the shared workspace, digital notes can be dragged, rotated and flicked by using typical multi-touch manipulations on the interactive table. It is also possible to change the color of notes or to delete notes. To facilitate the collaborative organization of notes into groups we included a simple clustering algorithm that automatically aligns and associates notes when released close to each other (see Fig. 6, a,b,c). Piles of notes can be created by releasing notes on top other notes. Clusters and piles can be moved by dragging them with multiple fingers (see Fig. 6, d,e,f). We designed these interaction techniques with the goal to imitate collaborative sorting actions at the whiteboard as closely as possible through multi-touch manipulations (T3). However, we traded some of the flexibility that is provided by paper artifacts against the possibilities introduced with digital representations. Yet, since all user action is focused on a horizontal surface, which is accessible to all participants, this might lead to more equal access and increased awareness of actions within the group.

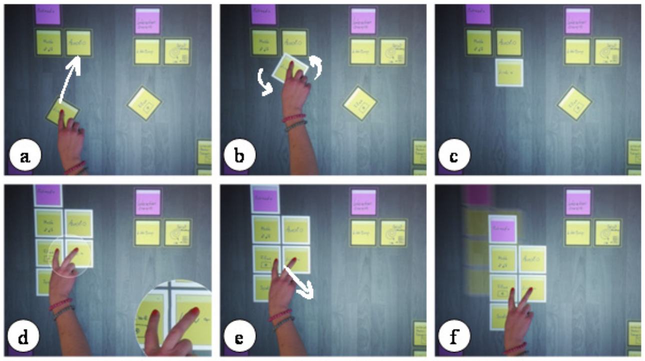

Figure 6. Clustering: alignment, association and dragging.

Collecting

When collecting notes or clusters from arbitrary locations within the shared workspace, it is a tedious task to move them individually via touch and panning manipulations across longer distances in the virtual workspace. In physical practice, notes can be collected into mobile piles (see Fig. 1, c). We replicate this ability by providing multiple two-sided tangible objects called "collector tokens" (see Fig. 7). By placing the colored side of this token on a digital note, it becomes selected (see Fig. 7, a). By turning over the token and placing it on the table with the blank side, selected notes are moved to this new location (see Fig. 7, b). This technique allows converting physical movement into virtual movement by preserving some of the original physical characteristics (T3).

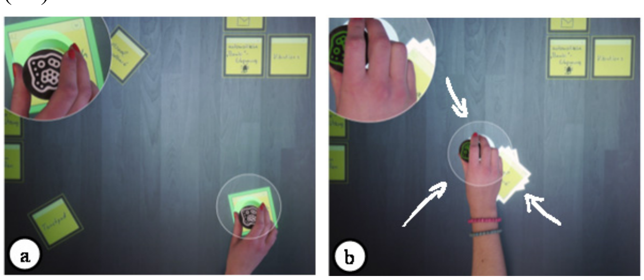

Figure 7. Collecting: selecting (a) and piling (b).

Highlighting

During discussion, deictic references on notes are often used as a form of communication and for coordination in the group (see Fig. 1, d,e). We augment these interactions by providing additional functionality. When touching digital notes, they are highlighted around their border with a glowing effect. Each highlight fades out after five seconds. This fading is also visible on the context display and thus can be used for deictic gestures across displays. When clustering notes, the fading glow implicitly communicates a history of actions that may help participants to remember the current focus of discussion if they got lost in the process. Therefore, this interaction technique focuses on promoting the chance for individual reflection and on fostering group awareness (T4,T5).

Focusing

Similarly, a physical "focus token" can be used to focus on a specific region within the virtual workspace during discussion (see Fig. 5, right). By placing this token onto the table, a region within the virtual workspace is selected for a detailed view on the vertical display. By turning the token (see Fig. 8, a), the users can increase or decrease the zoom-factor of the magnified view on the vertical display. By lifting the token from the table, the original view is restored. This interaction technique aims at improving group awareness and coordination. Because all other artifacts are temporarily hidden when using the token (except the immediate surroundings on the table), this technique is a powerful tool that allows placing focus on selected artifacts in order to moderate discussion and reflection (T5). It also minimizes physical movements and mutual blocking. However, particular dominant members of the group may also use this tool for gatekeeping.

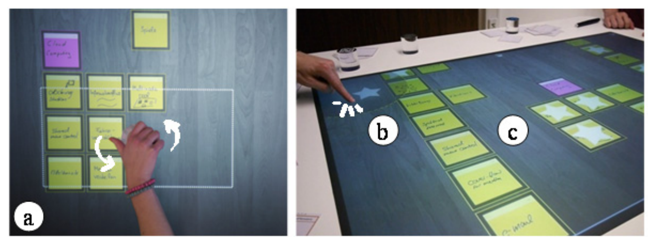

Figure 8. Focusing (a) and searching (b,c).

Searching

We integrated a lightweight search function based on the author of a note that is identified through digital pen IDs. By tapping personal symbols that are available in the *transfer spaces* at the corners of the table (see Fig. 8, b), the notes created by the corresponding user are marked with that symbol (see Fig. 8, c). This allows participants to look up the responsible author of a particular issue or idea during discussion. It also allows analyzing participants contributions to certain clusters and thus may provide information about consensus in the group (T5). This search function may introduce positive effects by reducing free riding, but may also have negative effects by increasing evaluation apprehension [22]. However, since notes are anonymous throughout the session and identity is only revealed on demand, this technique may stimulate individual contributions without putting too much pressure on participants.

Image Retrieval

When presenting ideas and issues it can be helpful to add additional information to make a clear point. Therefore, we added image retrieval functionality based on the content of notes. When placing notes into the *transfer spaces* at the corners of the table, five images that are related to the words on the note are retrieved from the web and displayed around the physical note (see Fig. 9). Users may then drag digital images along with a copy of the physical note into the shared workspace (see Fig. 9, a,b). Images in the workspace can be clustered along with digital notes. Hence, they can also be used to visually point out important clusters by adding representative images. This technique may have a positive influence on fixation effects because the selection of images can be used to further open up divergent activities (T5). Instead of using images from the web, this technique may also be used to augment notes with other data from custom design knowledge repositories.

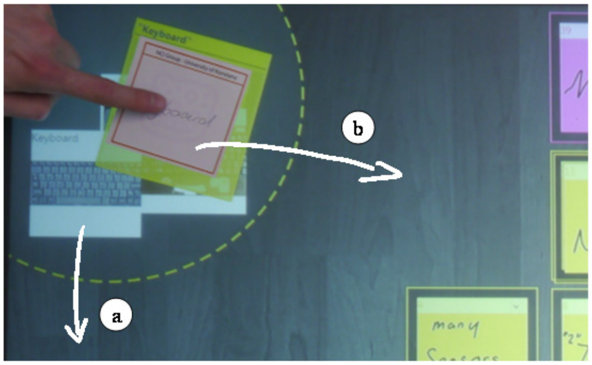

Figure 9. Adding images (a) along with notes (b).

Implementation

Our tool runs on a custom-built interactive table that measures 128cm x 157cm x 105cm. The non-interactive rim (20cm) was designed by considering guidelines for supporting leaning, personal workspaces and for avoiding involuntary interaction. The graphics are rear-projected with a WUXGA projector (1900px x 1200px). Multi-touch and object recognition is provided with IR illumination and three tiled XGA cameras (1024px x 768px). The vertical display measures 76cm x 162cm and features 4K resolution (4096px x 2160px). The software runs on two networked workstations with MS Windows 7. The interface is implemented using the ZOIL framework that integrates WPF multi-touch controls with distributed user interface synchronization and zooming functionality [12]. The size of the virtual workspace displayed on the vertical display can be adapted and therefore offers space for a very large number of artifacts. However, when increasing the space for artifacts, their representations on the vertical display become smaller and the effort for navigation on the table increases. We use ReacTIVision[1] for marker tracking and Squidy [16] for finger tracking. Data from Anoto's ADP-301 digital pens is received via Bluetooth by using the Anoto streaming API[2]. Text recognition is implemented using MS Windows 7 SDK. We use the Yahoo image search service for retrieving digital pictures from the web. All interface components are stored in a database system, thus allowing distributed access for later reuse of session results or for continuing sessions. Consequently, we also designed a client application that can be used on workstations. It allows for exploring created diagrams in a zoomable user interface and also enables data export.

[1] http://reactivision.sourceforge.net/
[2] http://www.anoto.com

USER STUDY

We conducted a preliminary user study with four groups of students (3-4 participants each, N=13) to investigate whether our tradeoff decisions were successfully implemented and how they might affect the workflow of the original technique. The goal of this study was not to measure the usability or efficiency of the interface itself. Rather we aimed to investigate general applicability and whether our tool successfully supports embodied practice (see Research Question). We invited the same students that took part in our initial study. Therefore, each participant already had experience in applying the affinity diagramming technique. All participants were graduate students in the area of interaction design. The average age was 25.8 years, ranging from 23 to 32. All had previous experiences using multi-touch devices. Participants were introduced to the functionality by one researcher who demonstrated the interaction techniques. Then they were given a design problem to solve collaboratively. Each session lasted about one hour. We observed the behavior of participants with two researchers and two video cameras. Moreover, participants filled out questionnaires before and after the sessions in order to assess their general perception of the tool design. Finally, a semi-structured interview was conducted in which participants were asked about their experiences with specific interaction techniques.

One of the key decisions we made was to preserve the physical workspace setting and thus provide a horizontal (table) as well as a vertical (wall display) surface (T1) as well as keeping the division into shared and personal spaces to allow for individual ideation and reflection (T2). However, to add power, we alternated the functionalities of these work surfaces in order to *ease the transfer* between them and to allow for a *smoother iteration between action and reflection*. Results of our questionnaires show that participants highly appreciated the table for collaborative manipulations, while stating that the vertical display supports reflection on the process. This included to identify isolate notes or to evaluate the structure of the diagrams like the size of clusters and the hierarchy of notes. Thereby, participants did not encounter any complications with the hybrid representation (physical/ digital) of the same notes during the session. In contrast, participants discovered great potential in the reuse of the physical artifacts after the ideation phase. For example, some kept browsing through their physical notes long after they had been digitalized in order to get inspiration for further ideas. Likewise, we observed that one group used multiple physical notes in order to move digital representations into clusters (see Fig. 10, left). Considering the personal workspaces, we found that participants efficiently used the rim of the table to create and sort their notes into sequences or piles. Nevertheless, we think the experience could be improved by providing a slightly larger rim for supporting more refined spatial arrangements. Participants also did not encounter any difficulties in transferring physical notes onto the table. This interaction was mostly performed smoothly, even for pre-sorted collections of notes. *Overall, we could not identify any violations of the original workflow or*

Figure 10. User Study: hybrid use of artifacts (left), simultaneous interaction (center), resulting diagram (right)

embodied practice with T1 and T2. Conversely, we could preserve important characteristics of the physical workspace whilst also enabling additional functionalities.

Our goal with T3 was to *support the handling of digital artifacts* within convergent activities. During our study, participants encountered no difficulties with clustering and piling digital artifacts on the table. The style of our multi-touch interaction techniques seems to be a close enough fit to participant's experiences with interacting with physical artifacts. Although it was possible for all group members to work on the table concurrently, we observed that simultaneous interactions were mostly negotiated in the group before they were executed, similar to the behavior we observed in real practice. This may be due to the fact that interactions of multiple users may still interfere with each other, e.g. when one participant tries to move the current view on the table and other users seek to work on clustering notes (see Fig. 10, center). Participants generally appreciated the automatic alignment and association of notes into clusters. However, due to inaccurate finger tracking, very quickly dragging clusters over a long distance on the table sometimes led to the interaction being interrupted. With regard to the collector token, we found that participants only rarely made use of it. They rather seemed to be quite emerged in the activity of interacting with the notes through multi-touch. This was further strengthened by the fact that the tokens were not essential for completing the session as the number of artifacts remained rather small. Therefore, a future study should investigate the usefulness of these physical tools in more detail. Nevertheless, we conclude that in our preliminary study, *the implementation of T3 did successfully support the original workflow of the design technique*.

We aimed to augment collaborative actions by *improving equal access and visibility of artifacts* with T4. In the beginning of the sessions, all participants focused primarily on the table because we constrained interaction onto this work surface. None of the participants stated that this had negative effects on their individual contributions to the process. Towards the end of the sessions, reflection became more important and participants more often worked with the context view. This tendency was further strengthened by the fact that none of the four diagrams fitted onto the table view and thus the context display was indispensible in order to gain a comprehensive overview over the diagram. Hence, it becomes even more important when dealing with a larger number of artifacts, a larger virtual workspace and more complex diagrams during more extensive design sessions. Participants did not express the need for the ability to manipulate contents directly on the vertical display. As a result, the vertical display did not get blocked in any of the sessions, thereby offering continuous visibility of artifacts to all participants. Hence, our study showed that *T4 successfully constrained the space for interaction while improving the visibility of artifacts*. However, a more detailed study may focus on measuring the potential benefits of T4 for accessibility and group awareness.

Our goal with T5 was to *augment reflection activities for improving coordination and group awareness*. Therefore, we implemented a focus token and the ability to search for notes based on the author. We also included the capability to retrieve images based on the content of notes. In our study, the focus token was primarily used for detailed explorations of notes that included a sketch or for focusing on images. We argue that due to the exceptionally high resolution of the vertical display that makes text readable from a larger distance and the ability to remotely highlight notes by touch, it was not required for notes that contain text only. The search function was hardly used during the sessions, but at the end of sessions. This might be due to the fact that it is hidden in the transfer spaces and is only available on demand. When we asked participants, some stated that it is most useful at the end of sessions or when reusing the diagram at later times because it might help to remember the process. This confirms our design decision to provide on demand access only in order to prevent negative effects on the workflow. The picture retrieval functionality was very well perceived among participants. We found that rather than searching for further inspiration, participants primarily tried to find pictures that helped to clarify the content of their notes. All pictures were eventually added to clusters (see Fig. 10, right). One participant stated that including pictures might help to quickly communicate the basic content of the clusters. Overall, the functionality clearly triggered lively discussions among participants. However, we found that it might slightly change the workflow of the affinity diagramming session when used by untrained people. In one group, it led to an early transfer of physical notes into the shared workspace as participants were curious to work with the pictures and thus placed their notes onto the table right after writing on them instead of waiting until their turn for presentation. In this case, the pictures also encouraged participants to transfer each note individually instead of digitalizing them in pre-sorted clusters. Yet, this is likelier to occur with inexperienced first-time users that are curious about the interface itself. Consequently, a future study should measure the effects on the workflow with a longitudinal approach. Overall, we can summarize that *interaction techniques within T5 generally did not conflict with the workflow of affinity diagramming* whilst providing additional functionality at the same time.

CONCLUSION

In this paper we presented our approach for designing reality-based interfaces for creative group work. Based on an observational study of the design technique affinity diagramming, we decided on specific tradeoffs to preserve embodied practice and for adding computational power. On the basis of these tradeoffs, we designed a workspace that integrates an interactive table and tangible tools with a vertical display. A preliminary user study showed that by combining this workspace with digital pen & paper and multi-touch interaction, we can still preserve the basic workflow of the design technique. The study also indicates that an additional vertical display may be used for supporting reflection-in-action and for enhancing the visibility of artifacts. Regarding our research question, we may conclude that we were able to preserve the general workflow by still adding some power with a digital tool. However, a more focused longitudinal user study with creative professionals and more extensive design sessions should be applied to measure the potential benefits that are introduced with the tradeoffs. Nevertheless, we argue that our approach represents a unique example for supporting important aspects of collaborative creativity with reality-based interfaces. At the moment, our system is limited to a maximum of five users due to the size of the table and available rim space. We are currently improving it by adding more power to our clustering functionalities and by providing a larger rim space. The general workspace design and some of the described interaction techniques can be adapted to other design techniques that share the phases of ideation, presentation and discussion. Therefore, in future work, we will also focus on extending the basic interaction model with other paper-based artifacts for supporting sketching techniques or creativity workshops.

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