The NiCE Discussion Room: Integrating Paper and Digital Media to Support Co-Located Group Meetings

Michael Haller[1], Jakob Leitner[1], Thomas Seifried[1], James R. Wallace[2], Stacey D. Scott[2], Christoph Richter[1], Peter Brandl[1], Adam Gokcezade[1], Seth Hunter[3]

[1]Media Interaction Lab
Upper Austria University of Applied Sciences, Austria
mi-lab@fh-hagenberg.at

[2]Collaborative Systems Lab
University of Waterloo, Canada
{jrwallac,s9scott}@uwaterloo.ca

[3]Fluid Interfaces
MIT Media Lab, USA
hunters@mit.edu

ABSTRACT
Current technological solutions that enable content creation and sharing during group discussion meetings are often cumbersome to use, and are commonly abandoned for traditional paper-based tools, which provide flexibility in supporting a wide range of working styles and task activities that may occur in a given meeting. Paper-based tools, however, have their own drawbacks; paper-based content is difficult to modify or replicate. We introduce a novel digital meeting room design, the NiCE Discussion Room, which integrates digital and paper tools into a cohesive system with an intuitive pen-based interface. The combination of digital and paper media provides groups with a flexible design solution that enables them to create, access, and share information and media from a variety of sources to facilitate group discussions. This paper describes the design solution, along with results from a user study conducted to evaluate the usability and utility of the system.

Author Keywords
co-located collaboration, interactive surfaces, pen-based interfaces, multi-user input, digital meeting room, design

ACM Classification Keywords
H5.3. Group and Organization Interfaces: Computer Supported Collaborative Work.

General Terms
Design, Experimentation, Human Factors

INTRODUCTION
Modern workplaces utilize a variety tools to aid workers in accomplishing their everyday tasks. In a typical workday an office worker may interact with paper media such as Post-its, paper documents, whiteboards and pictures as well as digital devices such as laptops, desktop computers, smart phones and PDAs. Collaborating in such environments often involves later converting ink-based work into a digital format by taking pictures of whiteboards and posters or by typing up digital notes for distribution and/or archival purposes. This transition from physical to digital media requires additional work and is often inadequate for capturing how the discussion has unfolded over time [19].

In this paper, we discuss a novel meeting room design that combines traditional collaborative tools with digital media: the NiCE Discussion Room. Our design integrates Anoto's digital pens [8], shared wall displays, and personal laptop computers to support group interaction through both digital and ink-based media (i.e. paper and whiteboard interaction).

Figure 1: The NiCE Discussion Room combines a large wall display, personal laptops and interaction with regular paper to support group discussion sessions.

Our discussion room (see Figure 1) provides the following features and capabilities:

- A large sketching wall facilitates real-time, simultaneous interaction between multiple participants.
- Participants can alternatively remain seated and interact via a paper interface. Private sketches can be drawn on the paper interface, and later shared with the group via the large sketching wall.

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- Personal laptops can also stream data to the large sketching wall via a physical video connection.
- In addition to direct interaction, tangible palettes can be used to interact with the large whiteboard display.
- Finally, the NiCE Discussion Room presents new interaction techniques for communicating and orchestrating group activities while working on a large, shared display.

To motivate the design of this novel interaction model, we first introduce design goals based on a review of the literature and on findings from our own requirements gathering investigations of co-located group meetings. We then describe the design of the NiCE brainstorming room, and in particular how its integrated design addresses the collected design requirements. Finally, we discuss preliminary results of a user study performed at a software company to test the performance of this design solution.

MOTIVATION AND DESIGN GOALS

The design of collaborative environments has flourished in the past decades as computing technology has matured. For example projects utilizing large displays, such as LiveBoard [7], Dynamo [16], i-LAND [29], PointRight [18], and WeSpace [35] support group meetings and presentations in co-located and remote collaboration setups. Similarly, technology advances have improved hardware interconnectivity and software compatibility, enabling new methods of user interaction across multiple devices, as demonstrated by systems such as Mighty Mouse [4], ARIS [3], and Perspective Cursor [21]. Research has indicated that the consideration of low-tech, established solutions and the physical design of a workspace can positively influence group behavior and performance [22, 30].

Dynamo [16] exploits multiple large screens to allow a number of users to interact simultaneously. The system is primarily designed for sharing digital media carried by users on mobile devices. In contrast to Dynamo, users of the NiCE Discussion Room can also work with traditional paper/notebooks and share these sketches with others.

i-LAND [29] and PointRight [18] support collaboration with multiple large, shared wall displays. Both systems use multiple touch-sensitive SMART boards with several limitations. First, the physical borders of the SMART boards divide the large workspace into multiple *individual* screens that are stitched together. Second, technical limitations of the SMART boards limit users to two-point interaction. Third, users cannot be identified by their contact with the surface. And finally, these systems focus exclusively on digital media and do not incorporate interaction with paper.

Both WeSpace and PointRight enable indirect control over the environment while remaining seated at the meeting table. In PointRight, users can control digital data on the wall by using mouse and keyboard and in WeSpace collaborators use a multi-touch table. We propose designing a collaborative environment where participants can alternatively remain seated and contribute discussion content on the board by using the paper interface and/or interact directly with the wall.

Rekimoto's Augmented Surface [24] and Caretta [31] demonstrate that tangible interfaces are a strong alternative when working with oversized displays. Building on this work, the NiCE Discussion Room provides both tangible and digital menus to support interactions within the environment. The results of a user study conducted within the NiCE Discussion Room suggest that tangible menus are useful alternative for supporting novel, inexperienced users.

A key contribution of this paper is the combination and integration of different features and interaction techniques motivated by the related work. We now discuss specific aspects of collaboration that were identified in the requirements establishment phase as important areas of concern with existing technologies.

Requirements Establishment

In order to gain a better understanding of the requirements for interactive workspaces that arise from real meeting and workshop situations, we carried out an exploratory field study at a large steel company. The field study included six meetings and workshops of the Information technology (IT) service division with internal and external customers. Each meeting took between 1 and 3 hours and covered topics such as business process modeling, requirements specification, evaluation of mock-ups, and project coordination. Each meeting included a variety of participants and occurred at different locations. Field notes were recorded throughout the meetings by one or more researchers. Structured interviews were also conducted with the meeting chairs after the meeting's conclusion.

The following sub-sections outline the design challenges that emerged from our analysis, and briefly describe how these requirements relate to work in the literature.

a) Multiplicity and Diversity of Tasks

Even though workshops and meetings are usually focused on a limited set of topics, they regularly encompass a multiplicity of tasks. For example a typical business meeting might include phases of brainstorming, decision-making, collaborative modelling, and planning. As each of these tasks entails different types of collaborative behaviour, a meeting room should be designed to be adaptable. Plaue et al. [23] describe this approach as "The Conference Room as a Toolbox", and argue that meeting spaces should provide groups with many different, and even redundant, tools.

Projects such as ARIS [3], Mighty Mouse [4], and PointRight [18], have approached this problem by providing an integrated technical environment; users of their systems are able to plug in multiple devices such as personal laptops in completing their work. However digital devices may not always provide the desired functionality in

supporting end users. For example, shared whiteboards and paper are often preferred when the task involves drawing. In order to support a wide range of functionalities, and provide choice to the end user, input and output devices should be selectable and seamless mechanisms for floor and access control should be provided. In the NiCE Discussion Room, we addressed these goals by creating a highly adaptable space in which people can interact with multiple (external) devices and work with traditional interfaces (e.g. paper) as well as with a large, shared interactive whiteboard.

b) Use of Space and Accessibility

The use of space during collaborative sessions is shaped by several potentially competing factors. The access to and manipulation of objects requires that meeting attendees physically reach for artefacts [33], and therefore be within close proximity to one another. However, in professional settings working in close proximity is often at odds with social norms and individuals' perceived personal space [34]. Similarly, users working collaboratively may wish to sit beside each other, whereas those working competitively often wish to sit facing each other [28].

The physical arrangement of displays, people and furniture are also important considerations when designing a collaborative environment. For example, Mandryk et al. [20] found that users seated away from a display may treat it as non-interactive. Wigdor et al. [36] found that seating position relative to a display can impact a users' ability to interact with content displayed on it. Ensuring that collaborative tools are readily available to users, both in terms of perception and physical access, can improve the ability of a space to facilitate collaboration. In NiCE, groups can dynamically reconfigure their workspace using adjustable tables and chairs.

c) Fostering the Creation of Shared Content

Shared content plays a fundamental role in collaborative work environments as it fosters the creation of a shared understanding, supports the coordination of activities and provides a shared memory for the group [25]. The creation of shared content also encourages the objectification of thoughts and ideas, a process highly relevant for creative and constructional tasks [12]. An interactive workspace also has to provide a means to create and manipulate shared content collectively; a process that is usually enabled via a shared workspace that facilitates concurrent content manipulation and editing by all group members.

However, a lauded advantage of shared workspaces - their ability to foster group awareness - can be detrimental in some social and cultural contexts: the "public" nature of a user's interactions exposes one's mistakes to others [14], and potentially invites criticism of one's actions and data before one is ready to share with the group [37]. Consequently, collaborative environments should provide both individual and shared workspaces, while enabling seamless transitions between these spaces, as discussed next. In the NiCE Discussion Room, users can sketch their ideas directly on a personal piece of paper, which can later be shared with the group via a large whiteboard.

d) Integration of Individual and Shared Spaces

Personal workspaces, such as those provided by laptops, paper notebooks, or a private desk area, provide a socially safe area for individuals to prepare ideas before presentation to the group. They can also facilitate subtasks that are carried out by different participants in parallel [17]. In contrast, a shared workspace supports activity awareness and coordination [10, 11, 32], non-verbal communication such as gestures [2, 10], and facilitates grounding via a shared visual reference [6].

Accordingly, to support individual work, participants should have access to both shared and individual workspaces where they can create and store their own content. However in order to provide an integrated collaborative environment, smooth transitions between individual and shared spaces should be ensured [26]. In the NiCE Discussion Room, both personal and shared workspaces are provided, as are seamless mechanisms for transferring data between the two.

e) Multiple and Interrelated Content Types

The types of content used in group meetings, and group work in general, are often quite extensive and heterogeneous in nature. For example software mock-ups, requirements specifications, and business process models may be used in parallel when a software development team is conducting a weekly progress meeting. This content may also be highly interrelated with relevant information spread across various resources such as Word documents, code files, websites or handwritten notes. In order to facilitate the use of multiple and interrelated content types, interaction metaphors that allow for easy navigation across disparate content should be provided. In the NiCE Discussion Room, participants have access to different data sources through layers presented on the large whiteboard, and can annotate this content as needed using whiteboard markers.

f) Integration into Overarching Activities

Meetings and workshops usually exist as part of a larger context of overarching activities and often depend on a combination of related project data, personal data and external resources. For example, stakeholders deciding on a location for a new restaurant may need to inspect a previously determined list of potential locations, consult personal correspondence with business partners external to the meeting, or look up tax rates provided by the local municipality. Hence, it is important that meeting attendees can easily transition between different types of activities in supporting collaborative work [34].

Traditionally, access to personal data has been provided through personal devices such as cell phones and laptops, as they afford a level of privacy not typically available on large, shared displays. Personal devices are also becoming increasingly ubiquitous as they become more powerful, portable, and interconnected. Consequently, collaborative

environments should provide mechanisms that support both the use of personal devices for personal work, and that enable content sharing between personal and shared workspaces to facilitate the integration of collaborative environments with existing work ecologies. In the NiCE Discussion Room, participants can access data stored both on personal laptops and in personal sketches from their paper notebooks.

THE NiCE DISCUSSION ROOM

The NiCE Discussion Room (Figure 1) consists of an enhanced whiteboard, paper, personal laptops, and specially designed furniture and software that integrate the physical components into a comprehensive environment that supports collaboration. Groups can use the NiCE Discussion Room as a platform for group work, and to support open, active discussions and seamless content creation and sharing. Within the room, a large display fosters the creation of shared content and allows for the integration of interrelated content types. Paper and laptop interfaces allow for the integration of personal workspaces, support a multiplicity of tasks, and provide a mechanism for the integration of overarching activities. Each of these components, and their respective functionality within the discussion room, will be described in detail below.

NiCE Whiteboard

The most visible component of the NiCE discussion room is a large (4.5m×1.1m) whiteboard that enables simultaneous multi-user interaction with either digital content (using digital pens) or traditional whiteboard content (using whiteboard markers). Interaction with digital content is enabled by using an oversized Anoto pattern in combination with the Anoto digital ink pens (ADP301) to track the position of the digital pen on the whiteboard's surface [13]. Pen interaction on the whiteboard is streamed in real-time to the system computer using the HID Bluetooth protocol with a latency of 50ms. Multiple Anoto pens can be tracked simultaneously, providing multi-user support across the entire whiteboard. Thus, users can work on collaborative sketches as well as on individual (personal) areas of the large whiteboard.

In contrast to [13], we propose a front-projection setup. The whiteboard's physical surface consists of three different layers:

1. The top surface is a special transparent (and highly robust) acrylic laminate, typically used for floors.
2. The second layer is a special Anoto-foil that allows the use of digital pens, and serves as a projection surface.
3. A metallic layer at the back enables the use of magnetic pins and palettes for special controls (e.g. tangible tool palettes).

The whiteboard's digital display is provided by three Hitachi CP-A100 short-throw projectors (1024 × 768 pixel resolution each), mounted above the whiteboard to provide minimal shadows during user interaction.

Figure 2: The Sketching Canvas, the default view for the large whiteboard. Users can sketch their notes on the sketching canvas using a variety of tools.

To support group work, the whiteboard currently runs the NiCE sketching application. The application provides simplistic sketching functionality – for example users can interact with the board using their pens and various tools to draw original content, or annotate and manipulate content imported from other paper and laptop interfaces in the room. Basic functionality is provided to users through tools such as pens, erasers, highlighters, and lassos. Each sketching canvas is of infinite size and can be panned in a manner similar to Photoshop [1], by using a moving-tool from the digital menu. It is also possible to zoom in and out in a sketching canvas using a dialing gesture [cf. 9, 27].

While editing or annotating, users can modify tool attributes, such as pen color or brush type, using either tangible tool palettes or digital pie menus. The digital menu is based on an occlusion aware menu design [5]. The tangible menu is an acrylic disk (9cm in diameter), which comfortably fits into a user's palm. It is based on Anoto's [8] printed dot pattern. The embedded magnets allow users to pin the tool palette directly on the whiteboard. Thus, the tangible menus can either be carried around to be used as a remote control (e.g. for switching between different pages during a presentation) or be placed on the whiteboard. Since each pen is uniquely identified by the system, the sketching application maintains unique parameters for each pen during a session.

Figure 3: Users can re-arrange sketched pages using the overview layer.

Sketched ideas can be moved within or between canvases by using a Pick-and-Drop [24] metaphor to avoid long drag-and-drop handling over the oversized wall display. If users wish to organize their sketches, new canvases can be

added to the session and managed through a separate overview layer on the whiteboard. The overview shows thumbnails of all sketched canvases of the current session, highlighting the currently active canvas with a red border (see Figure 3). Touching a canvas's thumbnail activates the corresponding canvas. Also, canvases can be deleted by touching the close icon on the thumbnail. The layout of the canvases can be changed by dragging thumbnails to a new position.

NiCE Paper

In contrast to most interactive boards, the NiCE sketching application supports seamless interaction with traditional paper (see Figure 4).

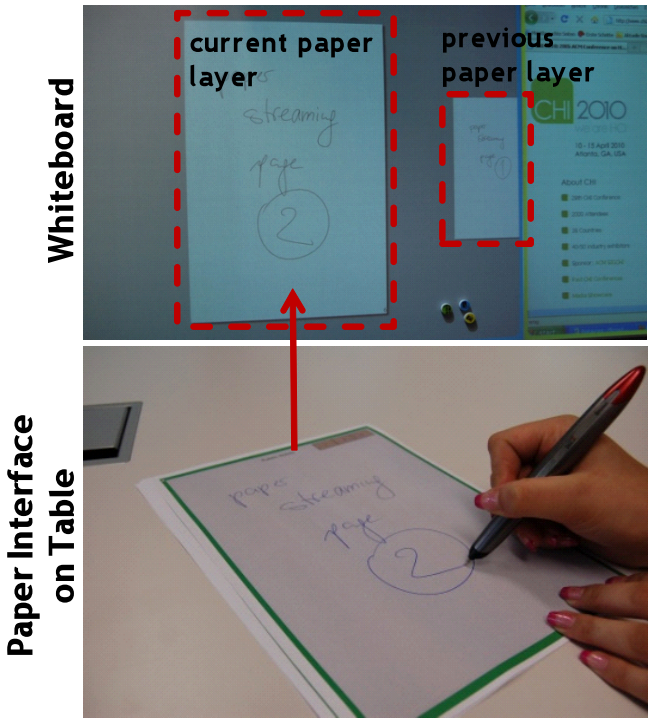

Figure 4: Users can sketch directly on a loose piece of paper (bottom). The strokes can be visualized on the whiteboard via an overlay (top) either at the time of creation, or later at a time of the author's choosing.

The NiCE paper interfaces are based on Anoto technology using DP201 pens. Unlike the pens used on the whiteboard, which have a stylus tip, these Anoto pens have a ball-point pen tip so that users can write permanent marks directly on the paper. Ideas sketched onto the Anoto paper are streamed in real-time to the system's computer via a Bluetooth connection. Users can choose to show or hide these paper-based sketches on the whiteboard, enabling both "private" and "public" modes of content creation. Content created privately can be shared with others on the whiteboard at a later time by activating the paper overlay on the whiteboard.

The paper supports two different modes of interaction: users can either prepare sketches during or in advance of the meeting (*private mode*) or stream data live during an active discussion (*public mode*). Sketches that are created privately can later be shared with the group by tapping an icon on the paper interface that shows the page's content in a paper layer on the whiteboard. Where previous projects, such as ARIS [3] and PointRight [18], have explored the usefulness of connecting personal and private digital workspaces, the NiCE Paper interface extends this functionality to paper-based media. The corresponding digital functionality is also provided by NiCE Laptop Input, and will be described next.

NiCE Laptop Input

In order to help integrate various activities that occur during or between meetings, the room provides a VGA to USB cable to capture content from connected personal devices such as a laptop. By invoking the screen capture layer on the whiteboard, the actual screen of the laptop is displayed on the whiteboard. On demand, users can take a snapshot of either the entire laptop screen or select a specific region. The snapshot then becomes part of the sketching canvas and can be annotated and modified as desired. This functionality is similar to the content re-direction techniques provided by the ARIS [3] and WeSpace [35] projects. The current version is limited by hardware constraints, updating the screen at 10fps.

This additional input enables users to easily integrate external applications into their meeting activities and to capture snapshots from their personal content and applications, without the need for additional software on the connected device. Our requirements study revealed that it was critical to avoid a complicated hardware setup. In particular, we determined that users wished to avoid installing any special software on their personal devices to be able to capture their data on the whiteboard, and that providing physical mechanisms to control display input has previously been found to be beneficial in the literature [22].

Whiteboard Overlays

As mentioned above, it is possible to overlay additional "layers" on the whiteboard over the sketching canvas. Three different types of overlay layers are available:

1. an overview layer: an overview of all sketched canvases,
2. a screen capture layer: an overlay showing a connected laptop screen, and
3. a paper layer: an overlay showing sketched content created on the paper interface.

These overlay layers facilitate non-sketching interaction, and the integration of additional data components and media into the sketching canvas on the whiteboard. Layers are shown or hidden using tangible magnetic pins, which are small tangible buttons that have functional icons printed on Anoto patterned paper that users can tap with their Anoto pens to invoke their associated functionality. The pins can be placed anywhere on the whiteboard, allowing for easy customization. Separate magnetic pins are provided for each layer type. To invoke a new layer, a user must first

touch the magnetic pin with their pen and then touch the sketching canvas where the assigned overlay layer should be placed (see Figure 5).

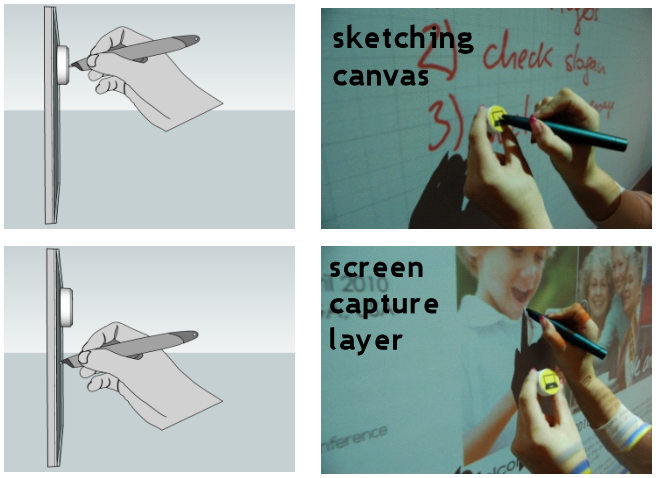

Figure 5: Using a magnetic pin to open the laptop screen capture overlay layer on the whiteboard. The user touches the magnetic pin (top), and then selects a location on the whiteboard to open the overlay (bottom). Once displayed, users can capture the entire screen or a specific region to edit on the whiteboard.

A short left/right gesture can be used to move the overlay screen to the left/right. A short vertical gesture towards the top of the whiteboard will hide the overlay. While several overlay layers can be used at the same time, allowing multiple data sources to be viewed simultaneously as in the WeSpace[35], it is not possible to open up two overlays at the same location on the whiteboard.

SYSTEM EVALUATION

In order evaluate the usability and utility of the NiCE discussion room, a user study was conducted involving small, co-located groups performing a collaborative design task. The study focused on the usability and potential of the integrated whiteboard and paper interfaces in supporting such group work and was designed with the following objectives in mind:

1. to understand the advantages of a digital meeting room, where the paper-sketches can be smoothly integrated,
2. to test the effectiveness of the NiCE Sketching application in facilitating group meetings, and
3. to observe real user experiences with the application interface: menu, tangible menu, layers, etc..

Participants

Thirty-nine participants from a local software engineering company were asked to test the NiCE discussion room. All participants were divided into 13 groups of 3. There were 7 females and 32 males between the age of 16 and 48 (M=29.2, SD=8.8). Twelve groups consisted of people who were either familiar or very familiar with each other. Only 2 groups were comprised of participants who were unfamiliar with each other. Participants spent an average of 8.9 (SD=3.4) hours a day on a computer and 3 of the users had experience with digital pens (e.g. Anoto pens). Participants reported having an average of 2.8 meetings per week (SD=3.45), where 21.4% of those meetings involve an external customer and 78.6% were internal only. Just over half of the participants (21/39) indicated that their meetings ranged from 30 minutes to one hour. Eight participants reported that their meetings usually last longer than one hour and the rest mentioned that their meetings usually last less than 30 minutes.

Task

Participating groups performed Hunter's [15] collaborative restaurant design task. To complete the task, groups of three participants worked cooperatively to design a restaurant in the nearby area. Each group member was required to assume one of three roles: architect, food planner, or financial planner. While working within these roles, groups decided on factors such as the type of tables and chairs the restaurant would contain, how color and décor should contribute to the restaurant's theme, whether additional walls should be added to the existing blueprint, what types of food should be on the menu, and whether the decided-upon choices fit within the provided budget.

The task instructions stated that the meeting was to be the first of 15 weekly meetings at the end of which the group would present their ideas to the mayor for approval. Groups were provided the following resources: multiple digital whiteboard pens, physical tool palettes, one Anoto ball-point ink pen and several sheets of Anoto paper, a budget, links to restaurant web pages, links to home centers, blueprints for the existing restaurant structure, and maps of the nearby area.

Procedure

Participants were welcomed and explained the purpose of the study. They were then given brief instructions on using the digital pens for sketching on both the whiteboard and a paper notebook, placed on the table. They were given 5 minutes of freeform play to become familiar with the system and discover system functionality. Next, participants were given a formal demonstration of the main features of the system with a special focus on paper interactions, the external connection with the provided laptop, and the overlays' functionality. The demonstration took approximately 20 minutes.

The study task was then explained to the group, and the task roles were determined. Participants were asked to use the sketching wall to perform the task and to try to use the paper and laptop input as appropriate to facilitate the group discussion. The group then spent 30 minutes performing the task, with no intervention. Finally, participants were asked to complete a post-study questionnaire consisting of 32 questions. The study session took approximately 90 minutes to complete in total.

All sessions were videotaped and observational field notes were taken by two researchers present in the room. Users' system interactions were captured in computer logfiles.

RESULTS

We now report an analysis of the interaction and user preference data gathered during the study. First, we report on an analysis of participants' interaction with the system, followed by analyses of users' self-reported opinions of the system and the task. We then discuss an analysis of perceived and observed group dynamics and interaction during the study. In-depth analyses of the video data captured during the group discussion task and of participants' initial explorations of the system are ongoing and will not be discussed.

System Interaction

We analyzed the tracked data from each stroke-sketching input, which resulted in approximately 1.2 million strokes across all 39 participants in 6.5 hours. Figure 6 depicts the activity map of all 39 participants.

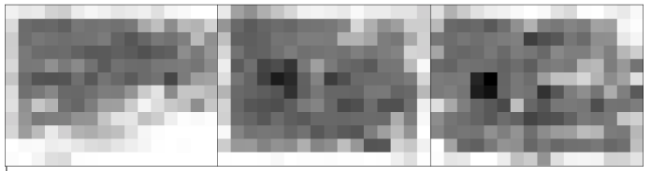

Figure 6: Activity map on the whiteboard showing the interaction of all 39 participants. Dark regions indicate high levels of activity; light regions indicate low levels of activity.

We subdivided the overall screen into a 48 × 12 grid and counted all pen activities in the corresponding tiles. Analysis of the system interaction logs revealed that 65.2% of the system interaction events occurred on the digital whiteboard, whereas 34.8% of participants' system interaction events occurred through the paper interface. Seven groups primarily used the whiteboard (M=83.5% of their system interaction time, SD=14.7%), two groups primarily used pen and paper and the laptop (M=71.4% of their interaction events were not on the whiteboard, SD=6.78%), and four groups used both interfaces equally.

Our analysis revealed that participants generally partitioned their interactions into separate regions of the display. This self-separation often corresponded to the three different projected screens, even though no visible boundaries were present on the whiteboard or introduced by the NiCE sketching application. For example, the upper two activity maps shown in Figure 7 indicate that each group member primarily interacted on a separate screen (each group member's interactions are indicated using a different RGB color). In this group, one participant dominated the interaction over the leftmost two-thirds of the whiteboard, and the other group members shared the rightmost section.

None of the groups used the tangible tool palette more than the digital pie menu. Seven groups used both the digital pie menu and the physical tool palette simultaneously. The screen capture overlay was used by 12 groups with an average of 6.15 times (SD=5.27 times). Only one group did not use the external laptop and therefore they did not use the overlay. Eleven groups used the paper content overlay with an average of 3.61 times (SD=4.25 times), and ten groups also used the overview overlay with an average of 2.23 times (SD=1.96 times). Nine groups used the zoom function (M=257.78 times, SD=277.41 times) and 11 groups used the pan function (M=539.77 times, SD=714.82 times) for having more space on the whiteboard.

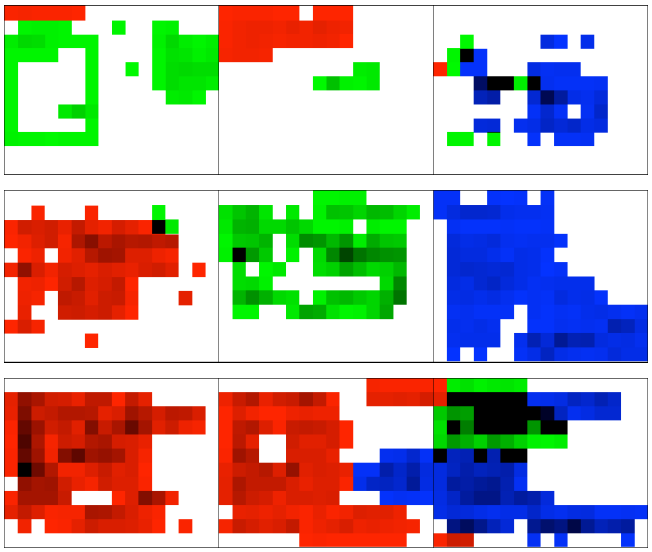

Figure 7: Activity map of three different groups, RGB colors indicating different users' interactions with the whiteboard.

User Preferences

In the post-study questionnaire we asked participants to rate the discussion room's usefulness on a 5-point Likert scale. 86.05% of the participants rated their general impression of NiCE as 1 or 2, with 1 being "easy", and indicated that they had fun working on the whiteboard. Participants reported that the open discussion space with the high table quickly initiated discussion. Moreover, three groups loved the bright room and the possibility of re-arranging the room's furniture. Four groups reported that the ability to combine different media (e.g. paper, PC, and whiteboard) made the system especially interesting for them.

Whiteboard

In general, 55.81% of participants reported being satisfied with their whiteboard interaction; three groups reported that they liked it because it allowed multiple group members to interact simultaneously and it provided a large work area. In contrast, some groups reported difficulties with its large size, as it was difficult to maintain awareness of others' activities. Few (18.6%) participants reported any problems with shadows from the front-projection setup, which were minimized by using short-throw projectors.

Table 1 summarizes the user feedback on the different interaction techniques. Most of the participants (78.6%) found that transferring data from the PC to the whiteboard was easy (rated a 1 or a 2). Data transfer from personal notes to the whiteboard was also well received by most

participants, with 91.4% of participants giving the system a 1 or 2 rating. 75.6% of the participants who used the screen capture tool found it comfortable and easy to use. Most reported problems were related to the use of the overlays; while 79.5% of the participants rated the use of the overlays as a 2 or 3, our anecdotal observations indicated that, for some participants, the 30 minutes of discussion was insufficient to understand and use this feature.

Physical tool palettes and digital pie menus

We also gathered user feedback on the choice of menus provided by the system. Twenty-one people preferred the physical tool palette over the digital pie menus and gave it the highest rating. These participants lauded the physical tool palette because it did not cover any screen space on the whiteboard and, thus, did not disturb the workspace.

Overall, the majority (76.2%) of participants found that handling the physical tool palette was easy (see Table 1). Participants did, however, report that the physical tool lacked feedback, a feature that would be very useful, especially for novel users. Eleven people preferred the digital pie menu, while seven people had no preference. 72.3% of participants had no problems with the digital menu. Those participants, who preferred the digital menu over the physical tool palette, reported that it was always there where they needed it.

Scale	How easy was the data transfer from PC to whiteboard	How easy was the transfer of data from the physical paper	How easy was it to take a snapshot	How easy was the interaction with the tool-palette	How easy was the interaction with the digital menu	How easy was the concept of the overlays?
1 (easy)	**31.0%**	**60.0%**	**45.9%**	**35.7%**	**30.6%**	7.7%
2	**47.6%**	**31.4%**	**29.7%**	**40.5%**	**41.7%**	**48.7%**
3	16.7%	5.7%	13.5%	16.7%	13.9%	**30.8%**
4	2.4%	2.9%	8.1%	4.8%	13.9%	7.7%
5 (difficult)	2.4%	0.0%	2.7%	2.4%	0.0%	5.1%

Table 1: User feedback regarding personal experiences.

Paper

Most groups also used the paper-interface. Most of the sketches created on the paper were completed at the beginning of a session. This behavior may have occurred as paper-based sketching was more familiar to participants, as reported in the post-study questionnaire. Thus, users may have needed time to feel comfortable with the newer digital-based interfaces. Additionally, users mentioned that they were more familiar with taking notes that cannot be seen automatically by everybody, that writing on the paper was faster than writing on the whiteboard, and that the paper notes were advantageous over whiteboard notes since they can be taken away after the session.

Group Performance and Process

Group performance and collaborative process during the study were also investigated to gain further insight into the system's ability to facilitate collaborative work. This analysis draws on participants' self assessment of group performance, video-analysis of seven groups, and the study groups' system interaction and coordination data.

Self-assessment of group performance and interaction

In the post-study questionnaire we asked participants to rate the difficulty of the task as well as the quality of group performance and interaction using a 5-point Likert scale, the results of which are summarized in Table 2.While about half of the participants (48.9%) rated the task as rather easy or very easy, 16.3% of the participants assessed the task as to be difficult or very difficult. The self-assessment of the achieved results follows a quite similar pattern; about half of the participants (48.67%) rated the results as good or very good, while approximately a quarter of participants (25.66%) were dissatisfied with the results achieved.

On the other hand, interaction within the groups was assessed more positively. About two-thirds of the participants (70.75%) assessed the overall interaction within the group as good or very good. Similar results were found for the discussion process (80.96%), the results of the discussion (63.41%) as well as the possibility to bring in one's own ideas (80.48%).

Scale	How difficult was the task?	How good was the result achieved?	How well did the group work together?	How did you like the discussion in general?	Are you happy with the result of the discussion?	How difficult was it to bring in your ideas?
1 (good/easy)	7.00%	20.48%	**34.17%**	**33.37%**	**26.83%**	**41.45%**
2	**41.90%**	**28.19%**	**36.58%**	**47.59%**	**36.58%**	**39.03%**
3	**32.60%**	**25.66%**	**21.91%**	19.04%	**29.25%**	17.10%
4	9.30%	15.42%	4.93%	0.00%	4.93%	2.41%
5 (poor/ difficult)	7.00%	10.24%	2.41%	0.00%	2.41%	0.00%

Table 2: User rating of task difficulty and group performance.

Creation and use of artifacts

To get an idea of how artifacts are created and used by participants, we carried out a preliminary analysis of the video-recordings of 8 out of 13 groups, and compared findings with data on tool usage tracked by the environment and participants' self-reports. The analysis revealed that participants were quite active and irrespective of the group all participants created or worked with at least one type of artifact, be it on the whiteboard, the paper, or via the laptop. While most of the groups also spent at least some time discussing artifacts together, we found that few artifacts were edited by more than one participant. Only in one out of the 8 analyzed videos did a participant directly add to someone else's artifact. This trend also becomes apparent in some of the activity maps, which indicate user's interaction with the system. For example, Figure 7 shows how the space of the whiteboard has been divided into three parts, each used by a single participant.

Individual and Group Work

Based on the video-recordings and data on tool usage tracked by the environment, we explored the interaction and coordination between participants. In general, results suggest that after an initial phase in which participants

discussed the task and decided on basic parameters for their concept (e.g. target population and opening hours), the group members split up and worked on subtasks associated with their respective roles. In this subtasks phase, primary design artifacts such as a menu, budget, or interior design were created, which were occasionally discussed on a bilateral basis or in plenary. Nevertheless, we found few attempts to directly aggregate or integrate the outcomes they had produced while working in parallel. Whether this lack of aggregation was due to the affordances of the room, an effect of the task, or an outcome of preexisting work practices, remains an open question.

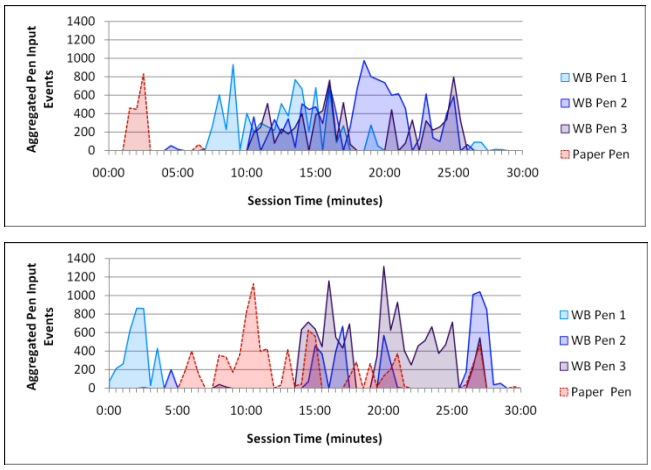

Figure 8: Interaction process graphs for two different groups' interactions with the whiteboard (WB Pen 1-3) and the paper interface (Paper Pen). The graphs show histograms of the amount of whiteboard and pen interaction from the beginning to the end of the experimental task trial. The top group started off using the paper interface, and then began parallel work at the whiteboard, while the bottom group used a mixture of whiteboard and pen interaction throughout their trial.

Figure 8 shows interaction process graphs for two different groups. These graphs illustrate the activities involving the shared Anoto paper (Paper Pen) and at the whiteboard (WB Pen 1-3) during their 30 minute task trials. One group (top) initially used the shared Anoto paper to document the basic parameters of the concept, before all three participants worked in parallel on the whiteboard. This process is analogous to using paper to sketch out a potential task solution before moving on to the whiteboard medium to work on a more concrete solution, which may indicate perceived flexibility of the medium.

The interaction process graphs reveal that the second group (bottom) made use of the available media in a much more varied way. They begin by working sequentially on the whiteboard, then switch to working with the paper interface and then work in parallel, with two people working on the whiteboard and one person working on the paper. These and other similarly diverse interaction process graphs from other study groups indicate that NiCE supports flexibility and variety in group working styles and task process, and both individual and shared content creation.

CONCLUSION

Through our work in creating an interactive environment that integrates digital and paper media, we have gained valuable experience and have made significant efforts toward our goal of providing an intuitive collaborative environment that fosters group work. The results of our evaluation suggest that the NiCE Discussion Room provided some distinct advantages in supporting group meetings. It incorporates paper and digital interfaces into a consolidated environment, its flexible interface supports a variety of collaborative styles, and users responded to the evaluation with positive reviews

Our analysis of participant interactions during the study suggests that not only were participants engaged in the task, and created a large number of artifacts, but also that these interactions occurred on all of the provided laptop, paper, and whiteboard interfaces. Variations in observed whiteboard use suggest that the flexibility of the sketching application was successful in supporting a variety of collaborative styles, including cases where a single collaborator dominated the use of the available workspace, or where contributions were made more equitably. Perhaps most significantly, the tools also supported both individual and group work, and transitions between the two modes of collaboration. Our analysis also provided an opportunity to investigate specific design choices, such as the use of overlays and physical and digital menus. Overlays were generally well received, and groups were able to successfully use these features to incorporate paper and laptop content into their whiteboard collaboration. However, field observations identified some difficulties with their use, and indicated that their design needs further study. Tangible menus were preferred by most participants over digital menus, and were lauded for not obscuring shared content and their pervasive availability. On the other hand, the lack of feedback afforded by the physical menus was cited as a disadvantage.

While the system evaluation presented in this paper was aimed at an overall assessment of the usability and utility of the NiCE Discussion room, further studies are needed to better understand the impact of the environment on the interaction and collaboration among users. Our next steps will include in-depth observation and qualitative analyses of the room's impact on interaction process and workspace awareness, as well as the practices that emerge when the room is used over a longer period by a team.

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