Making e-collaboration usable with Digital Affinity Diagram System(DADS)

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ABSTRACT
Collaborative affinity diagrams are a popular method for structuring idea exchanges. Creating an affinity diagram involves each member of a team writing individual points on sticky notes and making groups and links between these opinions with others by moving and arranging the sticky notes on a common wall or whiteboard. Many teams continue to use pen and paper to exchange ideas despite problems with usability. E-collaboration solutions so far have tried to provide more usable environments for affinity diagrams, but they have not been widely adopted. The Digital Affinity Diagram System (DADS) is groupware for digital sticky note creation and organization that integrates private input and common interactive spaces in one system. Using an extended dual-monitor setup to separate the two spaces, individuals can build stronger points by attaching supporting documents and media in a private space, and collaboratively organizing these points in a common interactive space synchronized across terminals. Our study compares the usability of the analog pen-and-paper method to the usability of the digital system we designed. We measure usability in a post-experimental survey, behavioral measures of system actions, and the System Usability Scale.

Author Keywords
CSCW;Collaboration; Affinity-Diagram; Brainstorming; Group work; Sticky-note ; Groupware

INTRODUCTION
Group problem solving involves exchanging and organizing ideas in order to come up with a satisfactory solution. Affinity diagrams, also known as the KJ method, are a popular discussion organizing tool[Kawakita, 1991]. Affinity Diagrams are often created by writing individual points on sticky notes or cards and, together with other participants, sorting the cards to uncover the points' similarities. Collaborative affinity diagrams can be useful tools for problem solving and organizing meetings where a concrete outcome is desired. The affinity diagram gives discussions structure and explicit goals, making them ideal for new groups working together or working with ill-defined topics. Collaborative affinity diagrams give groups a predefined method for a group to generate and refine ideas in search of the best. The KJ Method has even been used within the field of e-collaboration to explore ideas about digital collaboration systems: for example, Keary and Redfern [Keary and Redfern, 2012] used collaborative affinity diagramming to sort and organize points made in interviews with thought leaders and innovators in conferencing and collaboration.

Pen and paper implementations of affinity diagrams present some usability problems. Analog idea-exchange methods create social and psychological problems that are unrelated to the exchange of content, and may interfere with the efficiency of idea generation. Studies of face-to-face discussions reveal that production blocking[Diehl and Stroebe, 1987], fear of judgment by others[Gallupe et al., 1992], and social loafing [Williams et al., 1989] make pen-and-paper affinity diagrams less efficient than they could be. Organizations may be better served by tools that use private idea generation to lower the impact of social loafing or production blocking. Social loafing can be a response to the perception that with a group, the effort needed to complete a task is the same whether it is being done by a group or an individual, and thus, their required effort is reduced. Collaborators may also believe that others are not as capable as they are, and reduce their contributions in order to meet this 'least common denominator.'

Problems with analog discussions exist not only in the human element, but also in the technology used to create them. The original method developed to create collaborative affinity diagrams provided users with 3.5" square sticky notes to write their points on. This makes points easy to read and quick to understand by others in the group, but limits the amount of space available for expression. Methods that encourage more engagement with ideas may ultimately produce more creative solutions. While most uses of the affinity diagram employ sticky notes to represent individual points, the method does not require physical objects to represent users' ideas, and several digital implementations of the collaborative affinity diagram method have been developed, including our own. Indeed, the recent trend toward a paperless office means that e-collaboration and paperless implementations of collaborative tools deserve further research.

• UbiComp14, September 1317, 2014, Seattle, USA.

E-collaboration, described by Kock [Kock, 2005] as using electronic technologies among different individuals to accomplish a common task, presents many opportunities to change traditional methods for the better in these respects. There is a long tradition of computer supported collaborative work that we can build on to encourage interaction through technology and proxemics while avoiding face-to-face brainstorming problems by protecting an individual idea-space. Benford et al. offer a definition of computer supported collaborative work (CSCW) that is probably the most appropriate for the current work: it "examines the possibilities and effects of technological support for humans involved in collaborative group communication and work processes" [Benford et al., 1994]. Groupware describes the technology that emerges from CSCW principles[Grudin, 1994]. There are many groupware systems available for collaborative discussion and brainstorming. Not all groupware enables synchronous discussion or collaborative work space, but collaborative affinity diagram creation requires these features.

Collaborative affinity diagram groupware has both costs and benefits that developers and users should consider. For example, digital diagrams can make sharing the results of collaborative work easier by letting the system generate a report that includes users' points, comments, and the structure that groups create to organize their ideas[Judge et al., 2008]. Digital systems can make other actions during discussion easier, e.g. commenting on others' points and making commonalities between points obvious by sorting them into groups, or creating visual links between points. Some digital collaboration tools have focused on the problem of documentation[Miura et al., 2011]. Important points shared during discussion are hard to document because transcription by hand takes time away from other important tasks, and even if transcribed records of discussions exist, it can be hard to distill the most relevant points. It is also difficult to know how well ideas are supported, whether speakers are basing their opinions on real facts, or are simply charismatic enough to get consensus from the group. Digital systems that preserve a record of discussions can be useful to teams that deal with similar problems consistently, or to organizations that want to use historical comparisons as a source of change and improvement.

However, digital collaboration tools can also suffer from the problem of unnecessary novelty: users' initial impression of new technology is that it will be difficult to learn, and technologies that appear more novel are often rated less usable[Mugge and Schoormans, 2012]. Many examples of groupware solve usability problems by adding uncommon or expensive hardware and software to accomplish the same tasks that can be performed more easily with the old method. For example, Carpus [Ramakers et al., 2012] uses digital vision software to identify users' hands automatically while they are collaborating on a single digital screen. These addons are usually not practical for most organizations, and novelty is no guarantee of increased usability. In our design of this system we have made usability the top priority.

Another common problem with collaboration technologies is over-design or feature saturation. Enterprise-level tools are feature-rich and versatile but also monolithic and difficult to implement and adopt[Jeners et al., 2013]. A new generation of lightweight e-collaboration systems are emerging that solve this problem, producing environments that are lightweight additions to already familiar environments [Cite?]. Users of enterprise digital collaboration systems do not report good experiences, and are often resistant to their use, preferring face-to-face collaboration and analog methods with a secondary record via email.

Other e-collaboration tools may address one or two of these problems using technology, but none address all of them. Our main concern in this project is usability: to provide a solution to these problems that is usable by groups that need to improve their discussion context or incorporate digital media. The following review puts our system in context and outlines the specific problems we will address.

PREVIOUS RESEARCH

GUNGEN[Munemori and Nagasawa, 1996] is a pioneering digital collaboration system, perhaps the first to start using computer systems to help multiple users create, group and document collaborated ideas. Subsequent developments in the field include systems that focus on replicating the physical constraints of discussion in a digital format, as in Geyer and colleagues' AffinityTable[Geyer et al., 2011]. Their device allows users to create virtual sticky notes with digital ink and move them around via a multi-touch surface. Similarly, Miura and colleagues' Group KJ system uses digital pens to encourage as much similarity between the digital and analog process as possible, and focuses on the record-keeping advantages of a digital system[Miura et al., 2011]. Tse and colleagues [Tse et al., 2008] developed a system that allowed grouping, organizing, labelling and creating links between digital sticky notes in the public arena. Their system did not differentiate between users' sticky notes, which could create problems for identifying authors during collaboration. In addition, the inclusion of both personal and group territories in a large surface table does not address the possible overlap of territories and anxiety issues over shared space. A thesis by Jonas Minke[Minke, 2011] highlights the difficulty of searching for particular sticky notes in an affinity diagram, suggesting that digital systems should include an author tracking feature for easier identification of points. These systems can be grouped together based on their use of hand-written interfaces to create points, which preserves the physical interaction style of affinity diagrams but also limits the amount of information users can include.

Ballendat and colleagues'[Ballendat et al., 2010] system proposed access to a distributed space using a tablet, an idea that is also being adapted by [Rädle et al., 2013]; however, input in these systems still relies on written text instead of keyboard typing. The Firestorm tabletop by Claphyan and company[Clayphan et al., 2011] provides users with a central touch-sensitive tabletop interface at which they can generate points and post them using individual keyboard interfaces. Firestorm's gesture- and keyboard-based interface hybrid is interesting, but since reading direction cannot automatically orient toward the reader, sometimes target notes are upside down from a user's perspective. Developers that extend groupware to tables should be encouraged; touch-screen gestures are becoming more common as an interaction style, so incorporating common gestures in our system's repertoire can enhance usability and learnability. However, in the case of affinity diagrams, many current digital implementations contain the same errors in proxemics that the analog version does - individuals compete for space and public-board real estate instead of focusing on creating persuasive and relevant points.

Another line of research on point creation and organization comes from collaborative web-browsing tools, which allow users to annotate their discussion with evidence. Paul and Morris' CoSense tool enables group web-based investigation by making better sense of how individuals reach solutions and look for information to support them.[Paul and Morris, 2009] Recent developments in automatic content generation have allowed users to include supporting information from Wikipedia and have points proactively generated by their Facebook content during digital brainstorming[Gartrell et al., 2010]. In our experiences with affinity diagramming, we often found that a sticky note was much too small for some of the points that users wanted to contribute, especially if the process required people to express persuasive opinions. Small notes may also lead to more shallow points that, while they can be easily expressed in a few words, lack the depth necessary for some kinds of problems. Gartrell and colleagues' solution to generate depth with automated contributions may be helpful when a discussion lacks breadth, but it may sacrifice users' initiative and, to some extent, their privacy. Therefore, we developed an augmented affinity diagram system that draws from both digital implementations of the affinity diagram process and from collaborative investigation tools like CoSense.

Hypothesis

Traditional affinity diagram creation using paper and pen is not as flexible as digital affinity diagram creation, although it is more widely used. Current implementations of collaborative digital affinity diagrams have problems with usability that we have pointed out in the review above, such as problems distributing space between users and failing to utilize the flexibility of digital technology for storage and annotation.

We hypothesize that digital technology could help make content creation and editing easier. We hypothesize that sources would help users to better explain their points to others , and also make it easier for them to understand others' points. We think that technology can be used to make attach information sources to the points easier and more efficient. We hypothesize that digital presentation tools can be used to explain users points easier to explain and easier to understand. We hypothesize that good user interface design can increase the navigational capabilities of information flow between the users discussion s points leading to improved understanding of other users' points. Technology can also add efficiency to the organization of comments and feedback. Written comments naturally involve more movement and more resources than electronic comments, making digital comment and feedback systems more efficient.

We have observed that using sticky notes to create a collaborative affinity diagram lacks flexibility and efficiency. We hypothesize that a distributed screen solution could increase the flexibility and efficiency of organizing sticky notes during affinity diagram collaboration. This increase in flexibility could also give users a stronger sense of agency over card manipulation, observable as more card movements and actions, and resulting in higher satisfaction with the final result.

PROPOSED SYSTEM ARCHITECTURE DESIGN

The research we have reviewed above gives us four areas in which usability can be improved, where exchanges of ideas would commonly occur in group discussion, and where our digital system could improve upon previous work. These four areas are: Creating own points, Presenting own points, Exchange of opinions, and Creation of the affinity diagram.

Creation and Editing

The most important feature of a digital collaboration system is to give users the ability to quickly and simply create representations for their points that can be shared with other users. Our system provides an intuitive 3-column interface that enables users to create new items and populate them with content, and easily switch back and forth between viewing their own and others' points. The point viewing section is divided into two areas (Title and Contents) which we believe will help users formulate their points more clearly. The attachment feature of the system is also crucial here: since the fastest source for support documents and media is the internet, we needed to provide an intuitive link between the point creation area and sources of online information. One of the simplest functions is the cut-and-paste mechanism that can allow users to directly quote a website source. Users can also select images to include in the support for their point. We also allow users to capture a screen shot of any website if they wish to quickly include text and images, or the image is not in a standard format. URLs and images are quickly processed into a thumbnail format that can be expanded by the user or viewer.

Presenting

One major focus of this project is helping users express themselves better during group discussions. To this end, we decided to synchronize the opening and closing of cards using the expansion system so that it can be used as an explanation tool. During the Presentation phase of the experiment, users can expand images that they attached to their point card to further support their claims and points. Card and image expansions are synchronized across all users' common interactive boards and the central common view screen. The opening of images, URLs, and PDFs, zoom-in and zoom-out functions, and scrolling navigation are synchronized across all users so that the documents supporting presentation are part of a seamless shared experience. In addition, since users in the U-shaped seating arrangement may not be able to see the presenting user's hand, we built a special digital pointer tool that lets users highlight areas of the screen or indicate a certain passage of text. The digital pointer is incorporated across all image and page handling systems within the digital environment, including the internal browser.

Exchanging Opinions

An important function of group discussions is to exchange opinions, critique points and think of improvements. While the easiest way to refine ideas in a group is probably through conversation, recording and accurately interpreting conversations is problematic. Using a text-based comment system is a better choice for groups that need to keep an accurate log of discussions, refinements, and next steps. Also, text-based comments allow users to simultaneously add their opinions to the discussion without interrupting anyone else, reducing the impact of production blocking and social coordination. In the analog affinity diagram, comments are posted as new sticky notes on the same board as users' points. This can cause confusion between points and comments, and requires users to visually search for new comments to their own points. In our system, users can write a comment on any point, which logs their comment and attaches it to that point. This keeps the comment system on-topic and prevents users from getting confused. We also incorporated a notification system so that users can keep track of comments that are left on their points. This is represented as a small dot that shows up on the point creator's screen when someone leaves a comment. Users can cancel this notification by scrolling to the bottom of the list of comments briefly, at which point the system logs the comment as "read" and cancels the notification dot until a new comment arrives.

Organizing Cards in the Affinity Diagram

Using a distributed synchronized common interactive board between all users means that everyone in the team can, quite literally, be on the same page. DADS is optimized for two types of input (mouse and touch) making it a flexible system that adapts to different levels of device engagement. These different input types also contribute to flexibility in the creation of the affinity diagram. Grouping, moving, and linking points is easier due to features that are designed into DADS that allow users to manipulate points and groups, and annotate the common space using vector drawings.

Hardware Architecture

DADS was designed and developed at Tohoku University using the latest agile methods in software development engineering and strict usability testing methodology to achieve a consistent development pace. The team focuses on using only technology that is easily available on the market and leverages highly designed software development capabilities to create a high-quality product with superior user experience for supporting group discussion. The basics of the system can be seen in our previous work, the Discusys system[Widjaja et al., 2013]. The current system presents several technical and design improvements.

We designed a three-person seating arrangement with synchronous access for this experiment.. The current setup demonstrates what we imagine will be the most common use of the system, to facilitate face-to-face Affinity Diagram creation meetings for small teams.

- **U-shaped Seating Arrangement** - This seating design optimizes the dual monitor system and proximity between each participants. In our 3-person experiments, a large monitor acts as a shared common screen visible by all participants. Even though all secondary screens are synchronized, the large screen serves to assure participants that their manipulations and additions were recorded and synchronized with all other users' boards.

- **Extended Dual Multi-Touch Monitor** - For each user, their main laptop is located centrally, while their external monitor is to their left side, giving space for the mouse on the right side. We chose to use a multi-touch enabled monitor tilted at 30 degrees, to give users best access to the distributed common interactive space as a virtual 'drawing board,' and also allow eye-level contact for increased gaze awareness between users.

- **Server Setup** - Our server uses Windows 8, which acts as a database system and a synchronized input-output traffic center. The server does not require high performance for less than 5 simultaneous participants, and rather than high speed performance, the system prefers low latency in order to allow the high-frequency refresh of simultaneous workspaces.

Software architecture

The system's software was developed using Simple Object Access Protocol (SOAP) architecture, which relies on the exchange of information through XML information set through local HTTP protocol mainly developed under Microsoft's .Net 4.5 framework. We built the software natively using Windows Presentation Foundation (WPF), choosing Microsoft libraries over other .Net open-source libraries to increase compatibility across critical server, database, and client infrastructure. In addition, we also took advantage of the touch framework library that is currently maturing in Windows 7 and 8. This library allowed us to include a large screen multitouch monitor in our solution. Users' private input spaces were accessed on laptop systems running Windows 7, and the distributed common interactive space extended the screen with a 22" Iiyama multitouch monitor. The multitouch monitor uses a four-point infrared sensor to detect accurate multitouch from users, and has an 8ms response time. We chose a dual-screen design to increase information display clarity and focus for the users. While the main private input screen will act as each user's personal input interface, the common interactive space will focus on collaboration.

Distributed Real-time Synchronization System

To synchronize events and operations between severs and distributed clients, DADS relies on a client-server type of network socket infrastructure. The network socket service we choose is called Photon Engine developed by Exit Games[Exi,]. The network infrastructure used provides reliable low-latency data transport services on top of a user datagram protocol (UDP). Network socket can also be used as a Remote Procedure Call (RPC) system and server-side runtime for Application logic. The socket also acts as a delivery medium for code execution and callback between multiple clients and servers. For example, if the client calls some code on the server side, the server-side code executes and may return some arguments back to the client. The benefit of the network socket we is that it serializes the code logic by packeting it in small bytes of integers and creating a continuous call for event updates (up to 10 update calls per second) to simulate synchronous real-time behavior. Without Photon, we would have to deal with network packets directly, either using TCP/IP or UDP sockets. This would lead to an inefficient code execution stream, and increase latency in the system. Photon handles all instant notification needs, including: 1) All updates created by users, 2) All operations on the common interactive space editor (interactive user cursors, moving and editing any shapes), 3) Logging statistics of operations for further analysis. In sum, the Photon Engine server application will process all of DADS' main functions and automatically update any changes made to the SQL server database in real-time.

Private Input Interface

The private input interface is designed to maximize visibility and navigation capabilities for users viewing both their own points and others' points. Following network socket design standards, each discussion topic is treated as a separate room. Users are asked to give their name and select a color to represent their points on the common board. After identifying themselves, they choose a discussion room to participate in, and upon entering, each user can be identified by their chosen color. Giving each participant an identifying color parallels the practice of giving participants a unique color of sticky notes with which to perform the Analog affinity diagram task. This links points to their author and increases the personal dimension of interaction that can sometimes be lost in digital methods[Ballendat et al., 2010].

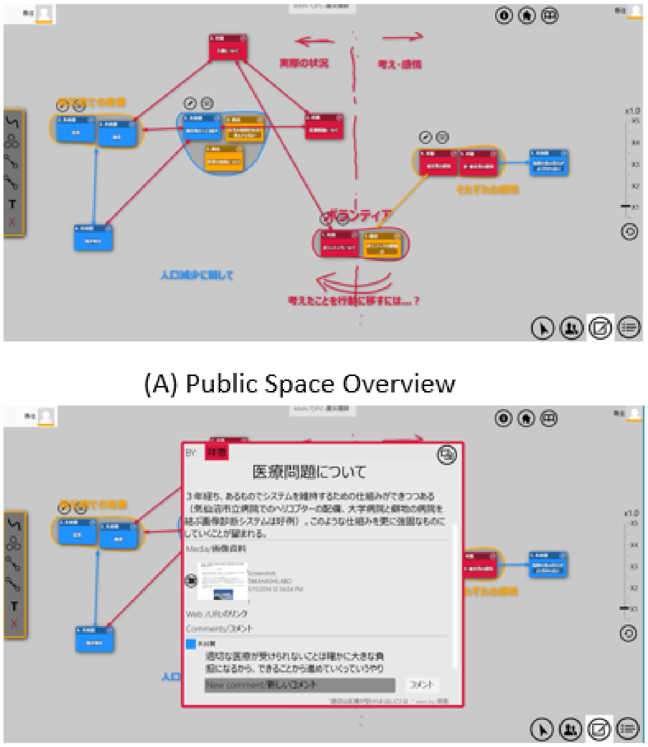
There are 5 separate areas in the private dashboard. The private input interface is a workspace intended for users to create points by inputting points and information. Figure 1 shows the 3 column dashboard: in the top right hand users can select different topics and switch from one topic to another; the middle column lists all the opinion titles written by each participant; the bottom right corner is where users select and view different participants' points; the lower center column lists the titles of other participants' points. Finally, the full screen right-hand column is where users construct their own points. Three distinct areas allow users to give each point a title, description, and source documents that support each point.

Users can switch freely between the input dashboard and a browser window when they are searching for supporting material. Early in the development phase, we observed that users often search for more information on the Internet to verify or affirm their points. To support this behavior, our system's source attachment function gives users the ability to attach articles or sources from the Internet to their points. We included three features that allow users to enhance their points with evidence: Internal Browser, Media Attachment, and Screen Shot. The system's internal browser makes it easier for participants to search of evidence to support their points. In addition, they can include URLs in their supporting material which will open naturally for other users. Media Attachment allows users to employ the familiar copy and paste functions to upload images from the web. While using the Internet browser, users are able to right-click the images they wish to upload and copy and paste the image url to our media text box in the system's private input form. The system automatically detects the presence and format of media, prompting users to correct badly formatted URLs and showing thumbnails of successfully processed images. We also observed that some users wanted to capture whole areas of a website, or graphics that are not in a standard image format, so we also incorporated a screenshot function. After pressing the screen shot button in our system, the internal web browser will be displayed, and users can scroll up and down to the desired part of the page. Clicking on the screen will initiate the capture window, and letting go of the drag window will capture the screen selection. The screen shot thumbnail is automatically displayed in the private input screen, indicating that the capture was successful.

Figure 1. Private Space User Interface

The private space interface allows users to easily create points related to a topic and populate them with information using familiar cut-and-paste mechanics. A basic interaction process would involve selecting the topic from the Topic window (pictured in Figure 1) and creating a new point in the User Point window, which creates a new card on the common interactive space related to that topic. Users can be identified as the author of a point by the color of the card. Users can also view all of the other points made in two locations: the common interactive board, and the bottom of the center column. This immediate availability may increase creativity by discouraging repetition and allowing implicit collaboration even before the collaborative affinity diagramming activity has begun. After creating a point, users can illustrate their point by adding supplementary information, images, and links in the Private Information Input window. Users can also use the built-in Internet browser in order to get more information or media to illustrate their point. When they are done adding information, the card is complete and they can create a new point, or browse other users' points, just as in the analog version of AD creation.

Distributed Common Interactive Space



(A) Public Space Overview

(B) In-depth Card Expansion

Figure 2. (A) Screenshot of common interactive Space interface with groups and links (B) Card Expansion: double tap gesture expands the selected card to display in-depth information including details, images and comments

In the distributed common interactive space interface, points written in the private input space are displayed as cards with the author's identity color. The card also displays the point's title and the author's name. These cards can be rearranged by touching and dragging them to a new location on the multi-touch screen.

We believe that successful collaboration requires the distributed common interactive space to be synchronized smoothly across different users. To achieve this goal, we utilized the Photon Engine, core technology from a multi-player game system that uses network sockets, and adapted the technology to suit our system. Participants are treated like players in a multi-player game system, with a unique identity and the ability to manipulate point boxes and enlarge the details of other participants' points. These manipulation input commands are constantly sent to the server, and updates are broadcast to other clients at up to 10 commands per second. Low latency will determine the smoothness of the distributed common interactive space's control and manipulation responses.

Five key features of the distributed common interactive space allow users to assemble an affinity diagram as easily - or more easily - than they can with the traditional sticky-notes-and-pen "analog" method.

- **In-depth Card Details** - Cards on the common interactive display only the title of the user's point. Users can expand the card details by double-clicking on the card. This triggers a window that displays all of the in-depth information that the author included in the point's supporting materials, including the description, attached links, and media sources.

- **Presentation Mode** - Card expansion actions are individually controlled by default. Users can also synchronize card expansions between users or across the whole teaming order to help users control and present their points easily, especially during the explanation phase of Affinity Diagram creation.

- **Grouping and Linking** - Grouping and linking cards can be accomplished using certain motions on the multitouch monitor. If a user presses the 'Group' button and touches cards on the common interactive space with a circular motion between several cards, a border around these cards is created, and these grouped cards can be moved as a unit. Groups of cards can be reorganized by moving any card within the group. Inserting new cards into an existing group happens if any 2 corners of an ungrouped card touches the group. If this occurs, it initiates a regroup function that allows users to insert a new card into the group. Users can link cards or groups to each other by pressing the 'Link' button and clicking two cards in sequence.

- **Vector Free Draw Annotation** - This feature allows users to draw a free-form vector object in the common interactive space that can be moved and re-sized. Editing these objects can be done with a stroke-by-stroke undo process instead of the cumbersome and graphically unappealing eraser function. Unlike the group boundaries and link lines, these objects allow users more flexibility to create symbols and diagrams on the spot, following the design principle that "a picture is worth a thousand words."

- **Commenting System** - This function replicates the commenting phase of the analog Affinity Diagram process by allowing users to comment on each other's points, ask questions, and write comments via the system. Users can expand any card and write comments on another person's points. In addition, users are notified of new comments via the system, which allows users to have real-time exchanges with each other.

Experiment Methods

Previous researchers have tested digital tools against their analog counterparts and shown that the digital tool has better usability. For example, researchers have compared analog methods of gallery writing to electronic gallery writing and found that it was a much more efficient method[Ghosh and Aiken, 2013]. In order to test the usability of our system against traditional methods, we set up two different idea exchange environments which we refer to as Analog and Digital methods. The affinity diagram process was originally developed to overcome some of the problems inherent in brainstorming and exchanging points[Kawakita, 1991]. The Nominal Group Technique (NGT) refines the process used in creating affinity diagrams. This technique is particularly helpful for groups that have not worked together before, are imbalanced in terms of extroversion/introversion, when the topic is controversial, and when some quantitative output is desired. Groups using NGT reported that this technique increased feelings of accomplishment and group efficiency compared to freely interacting groups[Gallagher et al., 1993].

During the creation of a collaborative affinity diagram, users go through 5 phases in the NGT:

1. Introduction and explanation
2. Silent generation of points
3. Sharing points by posting them on an open white board
4. Group discussion
5. Voting and ranking

This process was developed for problem-solving situations where groups had to agree on actionable next steps [Delbecq and Van de Ven, 1971]. Our process focused more on generating points and making associations between them rather than arriving at the best solution for a specific problem. Therefore, we eliminated the Voting and Ranking phase and ended our process after the creation of point groups by users.

Discussion topics for this experiment were designed to provoke many points and perhaps even heated discussion that would be moderated both by the NGT structure and by the use of digital tools. Both natural disaster recovery and nuclear energy have become important topics in Japan since the 2011 Tohoku earthquake. Naturally, most people in Japan have an opinion about how these crises have unfolded, so we thought these would be productive topics for discussion. We asked participants to discuss one of two topics in each experiment condition:

(a) **Nuclear Energy** - Discuss your opinion about the current Nuclear Energy policy in Tohoku

(b) **Disaster Recovery** - Discuss your opinion about the current Disaster Recovery situation in Tohoku

In the analog method, traditional tools are used including a whiteboard, colored sticky notes, and colored markers. points and comments are written on numbered sticky notes. Users write their point's title using a marker, and comments are written using a black pen. Comments are pasted below the relevant point note, creating a physical connection between the points and comments. To make the experiment equally balanced, we allowed users in the Analog condition to search the Internet and print out any sources they wished to use. Magnets were provided to help connect these printed materials to the point notes. In the Digital environment, users interacted with our system to conduct the experimental tasks. Before the experiment, participants were given instructions and a tutorial on how to use the system. Upon completing the experiment, participants were invited to participate in a survey comparing and evaluating the system's usability on a number of dimensions.

EXPERIMENT PROCEDURE

Materials and experiment instructions were in Japanese, the native language of all participants. Because of our sample's homogeneity, we could rely on participants' cultural identity to drive some interest in the discussion topics we chose. In this experiment, we compared the Analog and Digital methods of Affinity Diagramming within groups of 3 individuals. Having an odd number of participants per group prevents subgroups from forming - for example, 2 groups of 2. Users were given a different topic for each affinity diagram; they either discussed the recent earthquake recovery process in Japan, or recent developments in Japan's nuclear energy policy. Each group created one Affinity Diagram using the analog method and one in the digital method. These topics and the order of conditions was counterbalanced across groups, so that an equal number of teams had the Digital condition + Earthquake topic first, an equal number had the Analog condition + Nuclear topic first, and so forth. Each diagram went through 4 phases of creation, listed below.

Participants were welcomed and introduced to the purpose of the study and given a 20-minute overview of the tasks involved. If the group was assigned to the Analog condition first, they were given 30 minutes of instruction on how to create a collaborative affinity diagram using sticky notes, markers, and a white board. If they were assigned to the Digital condition first, they were given a 60-minute tutorial on using the digital system to create, support, present, comment on, navigate between, group, and link ideas in the creation of a collaborative affinity diagram. Participants had ample time during this tutorial to try out the system in the tutorial mock-up scenario, to become familiar with the system, and discover system functionality. The digital condition required a longer tutorial time in order to ensure that users were reasonably comfortable with the system. Users confirmed their familiarity with the system's functions in a quiz at the end of the tutorial. Groups completed all four phases of one condition using one discussion topic before switching to the other condition and using the other discussion topic.

- **Task 1: Point Generation and Attach Source** - Users create new points based on his or her opinions and perceptions of a single topic. During the Point creation phase for both Analog and Digital conditions, users can employ internet searches in two different typical behaviors. One is to start writing immediately, and use internet-based information to verify their points. The other behavior is to search for inspiration on the internet first, and write down points based on information discovered in their search. Both point creation patterns benefit from attaching internet sources (images or URLs) to their points. Each user was given 30 minutes to create 5 points on the assigned topic. They are given access to the Internet to search for support for their points. **Time: 30 Minutes**
- **Task 2: Present points to others-15 Minutes** - Even though points are always visible on the common interac-

tive space board, having points explained by their creator is more persuasive than merely reading them. Therefore, our goal was to build a system that helps users explain their points easily. We believe that the availability of sources to support points will increase users' confidence. A system that allows users to control and broadcast their sources during the explanation phase will increase ease of explanation for point creators, and increase the whole team's level of understanding. Each user was given time to present and explain their points to the other participants; **Time:15 Minutes**

- **Task 3: Exchanging comments** - Each point is unique, and in order to understand them team members must be free to question and critique. Thus, easy navigation to specific points must be a priority in the commenting system. The exchange of points is facilitated by the same turn-taking mechanisms that operate during conversation. Therefore, our system notifies users when a new comment has arrived, and users are able to reply immediately. The group was given 20 minutes to comment on others' points and reply to any comment posted to them. They were asked to write as many comments as possible across all the points, until the time was up. **Time: 20 Minutes**

- **Task 4: Affinity Diagram creation** - After commenting on each other's points, participants were asked to collaborate on an affinity diagram using the points created earlier, grouping similar points and linking related points using a Nominal Groups technique which was explained to them in the instruction phase. **Time: 15 Minutes**

After completing the task in one mode (Digital or Analog), groups were given a long break before returning to complete the experiment. All participants completed all 4 tasks in both analog and digital methods, for a total of 8 tasks in each experiment group. The total time needed to complete both conditions of the experiment (with breaks) was 5.5 hours per group, on average. To show the equivalence of the two methods, a snapshot of each experimental condition is shown in Figure 4.

(A) Analog Condition (B) Digital Condition

Figure 3. (A) Analog Condition: using sticky note and white board (B) Digital Condition using DADS with auxiliary multi-touch monitors.

INSTRUMENTS AND METRICS

We operationalize usability in three ways: a usability survey administered to participants, a more general System Usability Score, and several behavioral performance metrics. Our analyses determine which of the two methods is more preferred by users and whether DADS supports users in exchanging and organizing their points. We designed this study in order to explore users' interactions with our system and with each other. We created a detailed survey about specific features and affordances of the digital and analog conditions, and we also used the Standard Usability Survey to measure the digital system's usability and learnability. We collected data on both user behavior and users' self-reported experience, and our analyses highlight the relationships between behavior and experience. Correlations between survey items and behavior metrics are presented to explore some interesting relationships within the system.

Survey and Performance Analyses

We designed a post-experimental questionnaire with 15 1-5 Likert scale questions addressing how easy or hard it was to perform certain tasks using either the Digital or the Analog method. Low scores indicate less reported usability. Questions are listed below with a short item code so that graphs and tables can be more easily understood. Our specific questions were:

1. How easy was it to create points using this system? (Create)
2. How easy was it to edit points using this system? (Edit)
3. How easy was it to attach sources to your points using this system? (Attach)
4. How easy was it to explain resources and support for your points in this system? (Show)
5. How easy was it to explain your points to others? (Explain)
6. How easy was it to read other users' points in this system? (Navigate)
7. How well did you understand other people's points? (Understand)
8. How easy was it to read comments on others' points in this system? (Read)
9. How easy was it to write comments on others' points in this system? (Write)
10. How easy was it to reply to comments in this system? (Reply)
11. How flexible was it to create an Affinity Diagram in this system? (Flex)
12. How easy was it for you to cooperate with other group members to achieve the task in this system? (Teamwork)
13. How comfortable did you feel during the experiment? (Comfort)
14. How useful do you think this method is compared to the other method you experienced? (Useful)
15. How satisfied are you with the final Affinity Diagram that you made using this method? (Satisfy)

We measured several aspects of individual users' behavior in order to get a clearer picture of what users did in each of the conditions: number of attachments made, number of comments made, number of times a card was moved, grouped, or linked, and the amount of time groups took to create the final affinity diagram. We also calculated the number of moves per minute for each user; we view this measure as an indicator of the cognitive agility afforded by each system. Groups' behavior was recorded automatically in the digital environment. In the analog condition we used a GoPro HERO3+ digital video camera mounted on a jib in order to provide visual access to all users' movements. Video from the analog condition was hand coded by the first author.

We used paired t-tests to analyze the users' responses and determine whether the two experimental conditions were different from each other. This test is appropriate for our analysis because each participant generates data in both experiments; in essence, we are sampling each participant twice for each measure of the questionnaire and performance metrics. The analysis is based on the differences between the values of each pair - that is, one subtracted from the other. In the formula for a paired t-test below, this difference is notated as d.

$$t = \frac{\sum d}{\sqrt{\frac{n(\Sigma d^2) - (\Sigma d)^2}{n-1}}}$$

We chose p = 0.05 as our threshold for significance for the paired t-tests, reflecting a value of $\alpha = 0.05$. This value is commonly used in experimental psychology and human factors research, since these fields deal with hypotheses that do not require stringent levels of certainty in order for significant claims to prove true [Bross, 1971].

OBSERVATION RESULTS

Data collected from 8 groups of 3 for this experiment (N=24; 12 female and 12 male) is presented in the current paper. Participants were university students between the age of 18 and 24. All subjects are using mouse on the right hand which is best suited to the system design, one students, is a left handed students but keep using mouse on the right handed. Twenty Students comes from the STEM(Science, Technology , Engineering and Math) students and 4 students are Social Science students. . Twenty of the participants own a smart phone while two uses a feature phone. Eleven students reported using a dual-screen monitor in the past, and thirteen students had not used a dual-screen setup before.

We divide the result into 3 areas 1) Survey results and Usability Results , 2) Performance Results for checking efficiency 3) Correlation Data result to see the correlation between the survey and the performance. the first part we discuss the results of the survey with the focus on 1) content creation 2) Presentation 3) Comments 4) Understanding and Affinity Diagram and finally the 5) Affective Measures on the results, we then check on the usability results based on the System usability scale to prove that the system is scientifically usable. Second part we discuss about the results from the performance metrics to check for the performance

Creating and Presenting Metrics

An analysis of participants' answers to the usability survey questions is shown in the figures below. Paired t-tests were used to determine the relative strengths and weaknesses of the two methods (Analog and Digital), as perceived by participants.

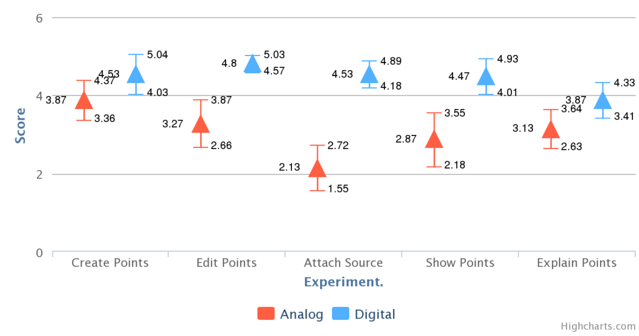


Figure 4. Usability Survey T-test Results

Participants reported that it is easier to conduct the tasks involved in creating an affinity diagram using the Digital method compared to the Analog method. The ease of creating, editing, and attaching sources to points was deliberately engineered into our system, as reflected by responses to the usability survey. Participants found it marginally easier to create Digital points (M= 4.37 (SD = 0.92)) compared to Analog points (M=3.87 (0.92) p <0.05). Participants also found the Digital editing function significantly easier (M = 4.80 (1.34)) than the same process in the Analog condition (M = 3.27 (0.90), p <0.01). Editing points in the digital environment involves familiar text manipulation, while in the analog environment participants must erase and re-write information, which may discourage them from editing. Our system's Attachment function proved quite usable, with rating for Attaching sources is significantly higher for the Digital format (M=4.53(SD =0.64)) compared to Analog (M=2.13, (SD=1.06), p<0.05). The presentation and expansion features of our system both contributed to better usability, since users report that showing points is easier in the Digital environment (M=4.47, SD=0.83) compared to Analog (M=2.87, (SD=1.25) P<0.01)). Users also report that it is easier to explain ideas in the Digital environment (M=3.87, SD=0.83) compared to Analog (M=3.87, SD=0.83, P <0.05). Participants found navigating between points in the new system (M = 4.33 (0.65)) significantly easier than in the traditional method (M = 2.50 (1.00), p <0.01), which was one of our primary goals in the design process. Participants' scores show us that the private input interface improves the most difficult tasks in the affinity diagram process: creating, supporting, and finding other users' points. These relationships are further explored in the correlation analyses.

Table 1. Full Experiment Self reporting Usability Survey result

	N	Mean	SD	SE	95%LCI	95%UCI	Median	Skewness	Kurtosis	P-Value
Create Points AN	24	3.83	1.01	0.21	3.41	4.26	4.00	-0.17	-1.33	0.09
Create Points DI	24	4.33	0.87	0.18	3.97	4.70	5.00	-1.03	0.06	
Edit Points AN	24	3.12	0.95	0.19	2.73	3.52	3.00	0.65	-0.49	0.00
Edit Points DI	24	4.58	0.65	0.13	4.31	4.86	5.00	-1.19	0.13	
Attach Source AN	24	2.25	0.90	0.18	1.87	2.63	2.00	0.91	1.46	0.00
Attach Source DI	24	4.67	0.56	0.12	4.43	4.91	5.00	-1.34	0.73	
Show Points AN	24	2.71	1.12	0.23	2.23	3.18	3.00	0.38	-0.60	0.00
Show Points DI	24	4.54	0.72	0.15	4.24	4.85	5.00	-1.81	3.64	
Explain Points AN	24	3.12	0.74	0.15	2.81	3.44	3.00	0.43	0.00	0.01
Explain Points DI	24	3.71	0.69	0.14	3.42	4.00	4.00	-0.36	-0.07	
Navigate Points AN	24	2.96	1.08	0.22	2.50	3.42	3.00	0.47	-0.66	0.00
Navigate Points DI	24	4.29	0.86	0.18	3.93	4.65	4.50	-0.95	-0.01	
Understand Points AN	24	3.08	0.78	0.16	2.76	3.41	3.00	0.94	0.91	0.00
Understand Points DI	24	3.88	0.74	0.15	3.56	4.19	4.00	0.18	-1.24	
Read Comments AN	24	3.25	1.15	0.24	2.76	3.74	3.00	0.02	-1.11	0.00
Read Comments DI	24	4.38	0.82	0.17	4.03	4.72	5.00	-1.18	0.71	
Write Comments AN	24	3.04	0.91	0.19	2.66	3.43	3.00	0.26	-1.16	0.00
Write Comments DI	24	4.67	0.56	0.12	4.43	4.91	5.00	-1.34	0.73	
Reply Comments AN	24	3.08	0.83	0.17	2.73	3.43	3.00	0.29	-0.71	0.00
Reply Comments DI	24	4.46	0.66	0.13	4.18	4.74	5.00	-0.73	-0.65	
Flex Affinity Diagram AN	24	3.25	0.90	0.18	2.87	3.63	3.00	-0.48	-0.09	0.03
Flex Affinity Diagram DI	24	3.88	0.80	0.16	3.54	4.21	4.00	0.21	-1.47	
Teamwork AN	24	3.58	0.93	0.19	3.19	3.98	3.00	0.24	-1.09	0.52
Teamwork DI	24	3.75	0.85	0.17	3.39	4.11	4.00	0.05	-1.02	
Comfort AN	24	3.46	0.72	0.15	3.15	3.76	3.00	0.47	-0.37	0.04
Comfort DI	24	3.92	0.93	0.19	3.52	4.31	4.00	-0.16	-1.31	
Usefulness AN	24	3.25	0.79	0.16	2.91	3.59	3.00	0.06	-0.72	0.00
Usefulness DI	24	4.46	0.66	0.13	4.18	4.74	5.00	-0.73	-0.65	
Satisfaction AN	24	3.42	0.72	0.15	3.11	3.72	3.00	0.62	-0.19	0.00
Satisfaction DI	24	4.33	0.64	0.13	4.06	4.60	4.00	-0.36	-0.86	

Organizing Comments Metrics

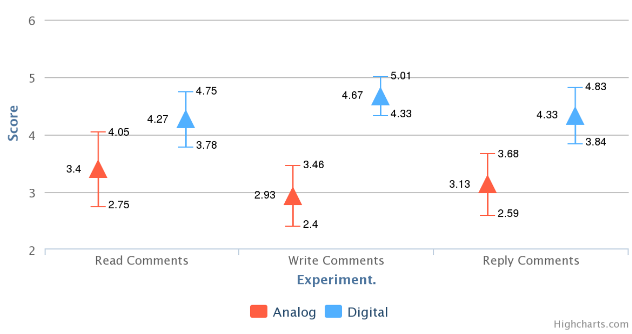


Figure 5. Analog and Digital T.test result for commenting

We evaluate the three tasks related to commenting in both methods: 1) reading comments 2) writing comments and 3) replying to comments. Users report a difference between the way they read in analog and digital. While all comment notes are shown in analog, in the digital version the comments are actually hidden until users choose to read them, and as a result we do not see a significant difference between analog (M=3.4, SD= 1.18) and Digital (M=4.27, SD= 0.88, p >0.10). However users report that it is easier to write comments in the Digital system (M=4.67, SD=0.62) compared to writing manually (M=2.93, SD=0.96, p <0.01). Finally, when evaluating the notification system for replying to comments, users rate the Digital format higher (M=3.4, SD= 0.9) than Analog (M=3.13, SD= 0.99) suggesting that it is easier to reply to comments using the digital interface.

Navigating,Understanding and Manipulating Metrics

Navigation (how easy it was to read others' points) reflects the usability of DADS' Private Input Space user interface. Digital environment navigation is preferred by users (M=4.47, SD=0.83) compared to Analog (M=2.93, SD=1.03, p <0.01) which is one of our primary goals. When we asked about how well users understood others' ideas, we discovered that it is easier to understand the discussion points in digital format (M=4.07, SD=0.8), compared to Analog format (M=3.27, SD=0.8, p <0.01). Collaborating on the affinity diagram was more flexible using the digital system (M = 4.13 (0.83)) than the analog system (M = 3.00(1.0), p <0.05), confirming superior usability of these functions in DADS.

Affective Metrics

We also asked users several questions that reflected their general feelings about the system: how useful it was compared

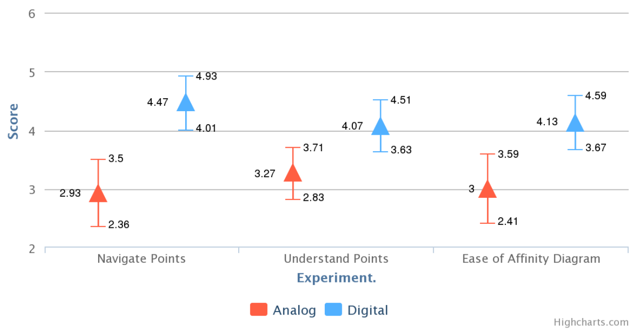


Figure 6. (A) Analog and Digital t-test result for navigation

to the other system, how comfortable they were using it, how satisfied they were with the end result, and whether they thought it improved their group's teamwork. Users felt that the Digital system was more useful than the Analog system for affinity diagram creation (Digital M = 4.53 (0.64), Analog M = 3.27 (0.96), $p < 0.01$), and they were more satisfied with the outcome of the Digital process (M = 4.20 (0.68)) than the Analog process (M = 3.47 (1.06), $p < 0.01$). Users were also more comfortable using the Digital system (M = 4.27 (0.70)) than the Analog system (M = 3.60, (0.91), $p < 0.01$), although this was not reflected in their ratings of teamwork (Digital M = 3.87 (0.83), Analog M = 3.53 (1.06), $p = 0.31$). Teamwork ratings may be statistically equal between conditions because each group ran in both Analog and Digital conditions, so their team across both systems was the same.

Performance Metrics

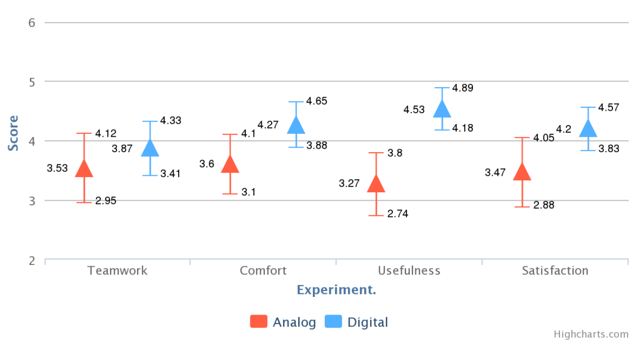


Figure 7. Analog and Digital t-test result for performance measures

We coded participants' behaviors in both the Analog and Digital conditions, counting the number of times cards were moved and re-grouped, as well as the number of supporting attachments users made to their points. Self-reports from our usability survey are supported by data from users' behavior. For example, participants felt that it was easier to attach sources in the digital system (M = 4.53 (0.67)) than in the analog system (M= 2.13 (0.85) $p < 0.01$). This is supported by a greater number of attachments associated with each idea in the digital system (M = 5.50 (3.49)) than in the analog system (M = 1.75 (1.19), $p < 0.01$). Navigation and attachment required fewer and smaller physical movements by the participant in the digital environment. Since the environment was itself digital, it was less cumbersome to look up new sources on the Internet to support points.

Table 2. Performance Metrics Results

	AN (SD)	DI(SD)	p-value
No of source attached	1.75(1.19)	5.50(3.49)	<0.01
No. of comments generated	6.79(1.98)	13.25(5.52)	<0.01
No. of card movement	8.04(4.31)	18.63(14.54)	<0.01
TimeAD (minutes)	7.11(2.11)	15.07(11.10)	<0.01

Time spent in discussion also relates to the number of card manipulations and re-grouping done by participants. Card movements per participant are calculated per minute during the fourth phase of the experiment, Affinity Diagram Creation. On average, users carried out 18.63 (SD = 13.63) card movement in the Digital condition compared to 6.79 (SD = 1.98) Sticky Note movement in the Analog condition. Time spent per group discussion in the Digital condition is also considered was 15.07 min (SD = 11.10), compared to 7.11 min (SD = 2.11) in the Analog condition. This may be related to more time spent on creating a more satisfying result and movement, the average Digital participant scored 4.33 (SD = 0.72) on satisfaction level compared to Analog at 3.42 (SD = 0.64). It is not surprising that users spend more time in systems that make them feel more satisfied, even if spending time can be otherwise seen as inefficiency. Since participants felt more flexible with the digital system, they may have been more inclined to extend their discussions and explore different links and re-groupings during the creation of the affinity diagram. Instead of viewing this extended time as a drawback, we view it as evidence of deeper engagement by participants with their own and others' ideas. Links and group creation demonstrate the integration of ideas into a framework for problem solving, which is the goal of affinity diagram creation.

Correlation Analysis

We present several correlations that explore the relationships between different survey metrics, and between these metrics and user performance. These correlations enrich our understanding of the relationship between user experience and user behavior in three separate areas: the content creation system, the relationship between presentation, explanation, and attachments, and the relationship between card movements and users' feelings of comfort, satisfaction, and flexibility. We believe that a causal relationship exists in group discussion: A usable system will enable more efficient thinking, greater understanding, and greater satisfaction with the system among participants, and these factors will emerge as more productive behaviors with respect to the tools people use to facilitate discussion. While correlations alone cannot show us a direction of causation, they are suggestive evidence that can point out good possibilities for further research and analysis.

Correlations allow us to see whether a rise or fall in one factor impacts another factor that we are measuring. For example, if users score our system high on the ease of making attachments, does this mean that they also make high numbers of attachments? A correlation coefficient can tell us whether change in one value is related to change in another value. We computed Spearman's rank correlation coefficients for select items from the questionnaire and performance metrics in order to explore the relationships between these factors. We chose this analysis method because initial exploration of the data showed some non-linearity. In order to be conservative, we chose a method that does not assume linearity or consistent variance throughout the data, Spearman's rank correlation (ρ)[Myers and Well, 2003]. Spearman's rank correlation is preferred over Pearson's r in cases where consistent variance in the data cannot be assumed. Spearman's ρ is calculated as follows:

$$\rho = \frac{\Sigma_i(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\Sigma_i(x_i - \bar{x})^2(y_i - \bar{y})^2}}$$

Statistical significance for Spearman's ρ , as for all correlation tests, is determined by comparing the current test to a 'null hypothesis' that there is no relationship between x and y. P-values of 0.05 or lower will indicate that a correlation is statistically significant. Spearman's ρ indicates the strength of the relationship between x and y; if this relationship is shown to be significant, then there is less than 5% likelihood that the strength of this relationship is due to chance.

Based on our analysis, we discovered that subjects' performance ratings are more stable in Analog compared to Digital. In all of the correlations we measured, there are 13 relationships that are significantly correlated in the Analog condition compared to only 8 in the Digital condition. We believe this is due to familiarity with the system; most participants are more or less familiar with analog methods, and they perform and respond in a more similar manner compared to a newly developed system that relies on each participant's level of experience with new technology. Despite these limitations, we present the results of our correlation analysis to provide further support for our hypotheses: a) Ease of attachment helps to increase the number of sources used; b) Number of sources improves explanation and understanding; c) Ease of navigation improves understanding; d) Flexibility also improves understanding; e) Flexibility is related to higher numbers of moves and greater satisfaction with the system. We address each hypothesis in turn below, as well as three additional correlations (f, g, and h) addressing the more subjective questions in our usability questionnaire: usefulness, satisfaction, and comfort.

a) Our correlation analysis does not provide any evidence that the ease with which the affinity diagram was created had any relation to the number of sources attached. Despite the results of the paired t-test analysis in which users reported that the digital environment made attachments easier, some users did not utilize the attachment function during the experiment, although all users tested this function during the training phase. The perceived usability of the attachment system seemed to have no effect on whether or not the attachment function was used. This may be related to the depth or specific content of users' points, which is outside the scope of this analysis.

b) The number of sources used is not correlated with ease of explanation or ease of understanding in either condition. However, ease of explanation and understanding are correlated significantly for the Digital condition (r_s = 0.45, p=<0.05). The evidence for this relationship is present, but less clear in Analog (r_s = 0.36, p=<0.1). Rather than the volume of sources, users' ease of explanation could play a larger role in their ability to understand other parts of the discussion.

c) The level of flexibility in creating the affinity diagram is correlated with levels of understanding in both conditions. For both Analog and Digital users, this coefficient is (r_s = 0.40, p=<0.05). This suggests that, rather than a relationship between understanding and number of sources, the flexibility of creating the affinity diagram is a stronger predictor of understanding during group discussion.

d) Ease of navigation is also strongly correlated with understanding in the Analog condition (r_s = 0.70, p=<0.05). However, this correlation is not strong or significant in the Digital condition. Instead, Digital users' ease of navigation is more closely related to comfort (r_s = 0.63, p=<0.05). Thus, it appears that ease of navigation in the two conditions may have different impact: directly on understanding for Analog users, and on affective impressions of the system for Digital users.

e) We also confirmed that ease of navigation between discussion points and flexibility are correlated in both Analog ((r_s = 0.44, p=<0.05) and Digital conditions (r_s = 0.47, p=<0.05). This may indicate that navigation and flexibility address similar functions or are mutually influencing.

f) Ease of navigation is highly correlated with usefulness for Digital users (r_s = 0.49, p=<0.05), while for Analog users the correlation is still positive, but not as strong (r_s = 0.325, p=<0.1). However, both conditions showed a relationship between the flexibility of organizing the affinity diagram and perceived usefulness. For Digital users, flexibility and usefulness correlated highly at (r_s = 0.57, p=<0.05) and Analog at (r_s = 0.40, p=<0.05). This helps us define flexibility as one of the key elements of usefulness, and thus closely related to usability.

g) We were not able to establish a correlation between flexibility and the number of moves in either condition. However, we found interesting potential evidence in the Digital condition where the number of moves is negatively correlated with the level of comfort(r_s = -0.36, p=<0.1) but positively correlated with the level of satisfaction (r_s = 0.3.8, p=<0.1). This could mean that more movements result in less comfort, but give users more satisfying results. However, Digital user performance varied more than Analog, so these data should still be considered preliminary, prompting further exploration of this new hypothesis.

Table 3. Spearman Correlation Matrix For Analog

	Edit	Attach	(p)Source	Show	Explain	Navigate	Flex	(p)Move	Understand	Comfort	Usefulness	Satisfy
Edit	1											
Attach	-0.016	1										
(p)Source	-0.189	$(a)0.298$	1									
Show	0.335	$0.307^{(*)}$	0.004	1								
Explain	0.134	$0.493^{(**)}$	0.123	$0.372^{(*)}$	1							
Navigating	0.177	$0.498^{(**)}$	-0.095	$0.459^{(**)}$	$0.364^{(*)}$	1						
Flex	0.399	0.152	-0.112	0.004	0.205	$(e)0.442^{(**)}$	1					
(p)Move	-0.081	$0.336^{(*)}$	0.197	-0.157	-0.011	-0.106	0.019	1				
Understand	0.337	$0.366^{(*)}$	0.129	$0.402^{(**)}$	$(b)0.361^{(*)}$	$(d)0.695^{(**)}$	$(c)0.401^{(**)}$	0.107	1			
Comfort	0.215	0.296	0.151	-0.006	0.249	0.331	0.360	-0.045	$0.417^{(**)}$	1		
Usefulness	0.260	$0.328^{(*)}$	0.022	0.193	0.248	$(f)0.325^{(*)}$	$(f)0.403^{(**)}$	0.044	0.326	0.212	1	
Satisfy	$0.355^{(*)}$	0.199	0.043	0.286	$0.509^{(**)}$	0.175	$0.497^{(**)}$	0.095	$0.407^{(**)}$	$0.439^{(**)}$	$(h)0.625^{(**)}$	1

Statistical significance=$^{(*)}$p<0.1; $^{(**)}$p<0.05;

Table 4. (DIGITAL) Spearman rho correlation coefficient

	Edit	Attach	(p)Source	Show	Explain	Navigate	Flex	(p)Move	Understand	Comfort	Usefulness	Satisfy
Edit	1											
Attach	0.108	1										
(p)Source	0.176	$-(a)0.295$	1									
Show	0.209	0.334	0.188	1								
Explain	-0.257	0.293	0.325	0.314	1							
Navigate	$0.477^{(**)}$	0.230	0.158	0.207	0.006	1						
Flex	0.137	0.051	0.127	0.131	$0.365^{(*)}$	$(e)0.471^{(**)}$	1					
(p)Move	0.250	-0.025	0.031	0.188	-0.123	-0.085	0.063	1				
Understand	-0.244	0.021	0.226	0.082	$(b)0.446^{(**)}$	0.213	$(c)0.397^{(*)}$	-0.184	1			
Comfort	0.195	0.051	0.063	0.035	0.237	$(d)0.633^{(**)}$	$0.439^{(**)}$	$-(g)0.356^{(*)}$	$0.371^{(*)}$	1		
Usefulness	$0.363^{(*)}$	0.047	0.294	$0.349^{(*)}$	0.211	$(f)0.494^{(**)}$	(f)$0.568^{(**)}$	0.049	0.232	0.315	1	
Satisfy	0.256	0.075	0.323	0.280	0.144	0.067	0.163	$(g)0.376^{(*)}$	0.082	-0.139	$(h)0.523^{(**)}$	1

Statistical significance=$^{(*)}$p<0.1; $^{(**)}$p<0.05;

h) Our last correlation shows that Level of Usefulness and Level of Satisfaction are highly correlated for both Analog ((r_s = 0.63, p=<0.05) and Digital users (r_s = 0.52, p=<0.05). This indicates that perceptions of usefulness and satisfaction are closely linked, and that improving the perception usefulness of a system can also improve user satisfaction.

System Usability Scale

The System Usability Scale(SUS) is a evaluation methods that provides an efficient way for users to evaluate a new system based on its usability and learnability[Brooke, 1996] from a industrial standardize point of view. It measures the usability, simplicity, integration, learnbility and confidence of users in operating any new system. The SUS has 10 questions, making it easy for participants to understand. It is reliable even in small sample sizes, and has been widely validated. The SUS asks participants to score the following 10 items with one of five responses that range from Strongly Agree to Strongly disagree:

a) I think that I would like to use this system frequently.

b) I found the system unnecessarily complex.

c) I thought the system was easy to use.

d) I think that I would need the support of a technical person to be able to use this system.

e) I found the various functions in this system were well integrated.

f) I thought there was too much inconsistency in this system.

g) I would imagine that most people would learn to use this system very quickly.

h) I found the system very cumbersome to use.

i) I felt very confident using the system.

j) I needed to learn a lot of things before I could get going with this system.

SUS is calculated as follows based on the items listed above (A-J):

$$SUS = \sum 8(a-1) + (5-b) + (c-1) + (5-d) + (e-1) \tag{1}$$

$$+(5-f) + (g-1) + (5-h) + (i-1) + (5-j) * 2.5 \tag{2}$$

$$\tag{3}$$

Positive and negative items are balanced by subtracting one from the score or subtracting the score from five, respectively. This scales all values from 0 to 4, with 4 being the most positive response. All scaled answers are summed and multiplied by 2.5 to convert the range of possible values to 0-100 instead of 0-40. The average industry score for evaluating usability system, based on previous research[Lewis and Sauro, 2009], is between 68 and 78 out of 100. This should not be interpreted as a percentage (i.e., ”68% usable”) but rather as a ranking.

Table 5. System Usability Scale Score Table

Statistic	N	Mean	St. Dev.	Margin of Error
Usability	24	78.0	12.49	5.54
Learnability	24	58.3	16.7	12.13
SUS Score	24	74.1	10.45	5.96

We calculated 3 objective scores for the digital system based on the industry-standard SUS instrument: Usability Score, Learn ability Score, and finally the overall SUS score[Brooke, 1996]. The usability score was **78.0**, which is above average, but the learnability score is **58.3**. Users still are not accustomed to the setup, and many said they needed more time to familiarize themselves with the system. Our system's overall score on the System Usability Scale was **74.1**, which compared to the industry standard of 68[Lewis and Sauro, 2009], indicates that the system has very high usability score and should be considered a viable alternative to traditional methods.

CONCLUSIONS

Based on our experimental results, we report that overall, exchanging and organizing ideas using a Digital Collaborative Affinity Diagram method is better received by users, compared to analog methods. We also found that users are more productive in terms of the number of sources and comments created in the digital system compared to the analog system. However, despite this preference among users, our research also shows that the analog system produces more predictable behavior and as a result, we are unable to clearly defend our hypotheses. Our research has clarified the usability and efficiency of this design, and our correlation analysis has suggested new hypotheses that can further research in the field of e-Collaboration.

Despite our earlier understanding of the impact of shared space on inefficient group discussions, we discovered that the way DADS currently implements distributed screens does not promote teamwork. This was a concern for us because collaboration depends on teamwork, so collaborative work environments should be designed to enhance teamwork in some way. We believe that the digital system's individual screens might prevent higher levels of perceived teamwork, so future experiments will test different screen configurations to see if the single-screen collaborative brainstorming systems are different in this respect. Still, we acknowledge that the current system maintains the same level of teamwork as the analog method despite groups working in an unfamiliar platform. Future experiments will test the theory that mediated interaction using individual screens fails to enhance teamwork.

We also discovered that while number of sources is an easy metric to calculate, it may not reflect meaningful understanding as much as users' perceptions of flexibility. Our original hypothesis assumed that users would utilize this function to enhance their points, and that this would lead to greater understanding of the discussion. However, our data show that flexibility in organizing the affinity diagram played a more important role in increasing understanding. We also present some evidence that the more moves users make in arranging the affinity diagram, the more satisfied they are with the end result; however, wide variance in the Digital subjects' data prevents us from making too strong a claim in this case.

Users spent a longer time creating the affinity diagram and engaged more movement in the digital environment due to the system design. These extra steps may be responsible for the increase in satisfaction with their results. Although we were not able to strongly prove this in our correlation, we believe this direction is worth further testing and exploration. In addition to movement, we also discover that despite more satisfaction with the final result, users do not feel as comfortable when they make more card movements in the Digital system. Thus, another avenue of potential research could be the relationship between satisfaction and movements despite discomfort with the novelty of the system.

Our data establishes a strong relationship between navigation and flexibility. We also discovered that navigation and flexibility have the greatest impact on usefulness. This has implications for the field of user interface design generally, and this relationship should be further explored in future research.

Our guiding principle in designing this system was to improve the usability of the collaborative affinity diagram process. How easy a digital tool is to use can have a great impact on how likely it is to be adopted by a group. Despite the current system's failure to significantly improve users' feeling of teamwork, we have established that users felt the digital environment is more usable than traditional methods. The SUS Usability subscore and the overall Usability score are both above the industry average of 68. There is room for improvement, as seen in the Learnability subscore. Our analysis of the System Usability Scale results for DADS shows that our system has the potential to be more usable as we increase learnability and improve training materials. Efficiency - or how quickly users can work in the system once they have learned the interface - is a component of usability. The enhanced efficiency of our system can be seen in the increased number of moves, number of attachments per source, and number of comments in the Digital system compared to the Analog system. It is easier for users to perform these actions (move, attach, comment), so they are performed more frequently and faster, contributing to more efficient communication of ideas.

Future Directions

This study shows many of the benefits our system can provide in helping users to exchange and organize their points better. However, it does not provide an in-depth analysis of the content of discussions as it emerges from different components of the DADS system. While we have focused the current paper on the overall usability of the system and the ease of creation, enrichment, and explanation, future research may explore the innovative possibilities of the presentation and comment features of DADS. Focusing on presentation and comments will give us deeper insight into the group collaboration process and how it can be mediated by technology. Our system gives users the opportunity to strengthen their points and deepen their understanding of the discussion topic by providing a system that encourages flexible in-depth thinking and individual investment in points that shape discussion. More detailed analyses could be performed on the current data to show whether there is a correlation in individual participants between ease of use and behavioral measures like number of actions taken or number of attachments made.

Future work may include the application of DADS to other innovative types of brainstorming and discussion. The private/common interface split and the grouping and vector draw features make nonlinear discussion types possible, and can also be modified to facilitate guided or directed brainstorming. We speculate that effective use of the presentation tool and comments is the main method by which users exert influence over the discussion. Mobile technologies could be used to augment these features or to supplement their use within the brainstorming context. This system also lends itself to real-world applications; if it is extended for use in industry, future iterations should include a report generation tool that formats all data from captured point cards and supporting material, and organizes it into a format that can be shared and distributed electronically.

Digital systems for enhancing collaboration have addressed many of the problems of efficiency and usability that are inherent in analog collaboration tools. DADS has built on previous work to improve a common way that teams share ideas, making communication more efficient during affinity diagram creation. This project also provides insight into the way distributed workspaces can impact collaborative discussion both positively (by improving navigation) and perhaps also negatively (by inhibiting feelings of teamwork). These insights, along with others we have discussed above, can provide new and fruitful directions for researchers in computer-mediated interaction to explore.

ACKNOWLEDGMENTS

We would like to extend our gratitude to Tohoku University for providing laboratory facilities, Various open-source communities that supported the software development, numerous volunteers that participated in the testing phase by giving constructive feedback to improve system, Japanese MEXT for government funding and scholarship.

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