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

William Widjaja

Department of Management of Science and technology Human interface lab, Tohoku University Aobayama 6-6-01-2, Sendai, Japan william.widjaja@most.tohoku.ac.jp

# 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 dualmonitor 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 penand-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 tried and tested method 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, although they are still popular [Holtzblatt et al., 2005]. 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.

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. 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 [Radle 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.

# HYPOTHESES AND PROPOSED SOLUTIONS

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. The research we have reviewed above gives us five specific 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 the systems previously described. These five areas are: (1) increasing the efficiency of content creation, editing and navigation; (2) improving capacity for information source attachment; (3) making presentation easier; (4) organizing and documenting comment exchanges; (5) and increasing flexibility in collaborating on the affinity diagram.

**(1)Efficient Content Creation and Editing** While most current usability research does not focus on content creation and editing systems, we hypothesize that digital technology can make content creation and editing easier in the context of collaborative affinity diagrams. We designed our system to provide a dual screen interface, where one screen is dedicated to creating and organizing one’s own points. This design feature is intended to give users the freedom to focus on thinking about and creating contents during the idea generation phase of creating the affinity diagram. There is a delicate balance between providing enough private space to users and encouraging them to use common space as a way to promote idea exchange. The division between public and private space will also promote the efficient creation of points by enabling users to generate points without suffering from production blocking. We also hypothesize that good user interface design can improve navigation and increase information flow between users’ discussion points, leading to improved understanding of other users’ points. 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. Users can toggle between their own and others’ points quickly and without using a menu, which will improve the efficiency of navigation. Users are identified by a unique color associated with their points both in the private interface and on the common board. It was important to us in designing the system that we retain familiar design features that make users comfortable with input methods, while also making improvements that enable users to collaborate with each other smoothly and efficiently.

# (2)Attaching Internet Sources

We also found no current research that focuses on the effectiveness of external source use during computer-mediated discussions. 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 make attaching information sources to points easier and more efficient. Since the fastest and most familiar source for support documents and media among our population is the internet, we needed to provide an intuitive link between the point creation area and sources of online information. The attachment system that we have designed for DADS allows users to support their points using multimedia sources. 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. In analog affinity diagram creation, people would be able to easily print materials and paste them on the board next to their point; however, a system that integrates source attachment functions will more efficiently promote the use and understanding of sources that support users’ points.

# (3)Presenting

Technology has often been used to enhance and facilitate the presentation of information to groups. Part of our integrated system is a presentation tool that can be used to make points easier to explain and easier to understand. Our proposed solution capitalizes on users’ separate screens: since each user has her own screen, presentation can take place on a distributed synchronized screen in which discussion points are in card format, with only their title displayed. Details for each point can be expanded on all users’ screens synchronously, under the control of one user at a time, so that each user can present their own ideas. When the system is in presentation mode, card and image expansions are synchronized across all users’ common interactive boards and the central common view screen. While in this mode 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, a special digital pointer tool lets users highlight areas of the screen or indicate a certain passage of text.

**(4)Organizing Comment Exchanges** While we acknowledge that speaking would be an easier and faster way to exchange comments, one drawback of speech is that it is hard to maintain a record of what was said. Since discussions involve multiple points, collaborative discussions can benefit from a method for coordinating which point should be discussed next. 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. However, hand-written comments naturally involve more movement and more resources than electronic comments, making a digital comment system a more efficient option. In our system, users can expand any card and write comments on another person’s points during the comment phase. In addition, users are notified of new comments via the system, which allows users to have real-time exchanges with each other. 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. While using sticky notes to record comments on other sticky notes is intuitive, an integrated digital system will allow users to more easily organize and document exchanges of comments.

**(5)Flexibility in Creating the Affinity Diagram** Based on our observations that using sticky notes to create a collaborative affinity diagram lacks flexibility and efficiency, we hypothesize that a distributed screen solution can increase the flexibility and efficiency of organizing points using this technique. However, one way that analog affinity diagrams are often more flexible than digital collaboration is that users can arrange sticky notes more naturally, using familiar movements. We have observed that touch interfaces such as smart phones and tablet computers have become more popular because interaction with this interface style is more natural than using peripheral devices. The multitouch interface in DADS gives users intuitive contact with arranging and grouping points and drawing illustrations that help explain their points. Synchronization across distributed screens will also give users a stronger sense of control over card manipulation, observable as more card movements and actions, and lead to higher satisfaction with the final result. These capacities will encourage users to participate more effectively in creating points and discussing them with the group, move and re-arrange points more often, and ultimately lead to greater satisfaction with overall results. We have made grouping, moving, and linking points easier in DADS with three features: vector drawings, smart groups, and arrow linking.

*Vector Free Drawing*

Previous digital collaboration systems have allowed users to draw in collaboration, but these drawings quickly become confused and overlapping. Unlike traditional drawing functions in collaborative creation boards, DADS proposes a drawing system that creates vectored image components from each free-form drawing on the common board. Because users’ drawings are converted to vector images that can be moved and resized, users have more flexibility to create and re-shape their own objects on the board and helps users organize their drawing assets.

*Smart Groups*

Analog affinity diagrams require users to make groups manually that cannot be moved as a unit. However, grouping in computer-based collaboration can involve complex un-grouping and regrouping steps before the new group is formed. DADS uses a group and regroup function that allows users to create and reorganize groups easily. Users can reorganize groups by moving individual cards into or out of the group. The group flexibly re-forms according to each user’s idea of what points should be in each group.

*Arrow Linking*

In analog discussions, users can draw linking arrows between two points or groups to point out causation or relationship. However, this link needs to be redrawn if the group is changed. DADS’ linking system is a simple two-click process that allows teams to have flexibility in constructing and changing the categories in which they group points during discussion. Linking arrows move with the group when users move a group of points, and can be deleted and re-linked as needed during discussion.

The hypotheses that we have discussed in detail above have clear implications for the design of a collaborative affinity diagram system. The functions that are required by the system should be reflected by the form of the system’s hardware and software. Below, we explain the system infrastructure that supports the features that we hypothesize will improve user experience in creating a collaborative affinity diagram.

# System Infrastructure

To solve some of these challenges through digital collaboration, we have based the current system on our previously developed system, Discusys[Widjaja et al., 2013], that has already addressed several of these challenges. Our goal in creating this system was to build an integrated system from the ground up that makes collaborative affinity diagrams easier.

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| --- |
| Figure 1. Client, Database, and Server Levels of System Infrastructure: Hardware and Software Setup |

The physical setup of the system is shown in Figure 1. Users sit in a U-shaped configuration that we selected based on Kendon’s work on group dynamics [Kendon, 2010] to closely mimic the structure of group discussion. Each user has two screens that separate the private point generation interface (laptop) and common display and presentation space (multitouch 22” Iiyama monitor), and all users have equal visual access to a large version of the common display mounted on the wall. The private input interface is displayed on a laptop to maximize users’ comfort and familiarity. The multitouch monitor is set up at a 30-degree angle from the desk, which serves two purposes: (1) it maximizes joint eye gaze between users during discussion which promotes engagement across the group, and (2) it gives users a more natural angle of access between their hand and the screen for movement gestures and drawing, similar to an artist’s drafting board. The multitouch monitors are fully synchronized across all clients and with the large common display, so that collaborative manipulations can be seen by all users at once.

*Multiple Client Infrastructure*

The client interface was designed using Windows Presentation Foundation (WPF), which we selected so that the system could render high quality graphics (vector graphics and typography) and runtime animation, important for the ”drag and drop” movements involved in grouping virtual cards using the multitouch monitor. We developed the touch screen interface using Microsoft PixelSense SDK, for backward compatibility with Microsoft Windows 7. Microsoft PixelSense builds in a basic multi-touch gesture repertoire including pinch to zoom, flick, drag, and double-tap to support user interaction. DADS

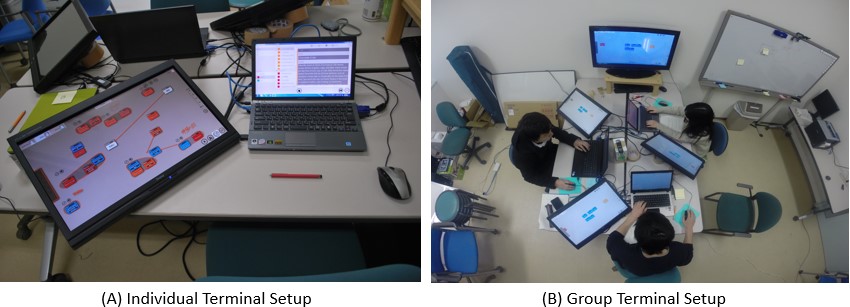


Figure 2.(A) Single Individual Setup with Dual monitor (B) Group

Setup with U-shape seating with a main monitor at the end of the table

client interface also has traditional mouse support, used in the private input interface, giving users two options for manipulation. Data from actions in the client interface (for example, moving a card or creating a new point) is stored in a database and synchronized by the network socket server.

*Database Infrastructure*

All data is housed in a single database utilizing SQL Server 2008 R2 engine. The database map is designed using ADO.net Entity Framework, an object-relation mapping framework. ADO.net Entity Framework is designed for managing information using four basic commands: Create, Read, Update, and Delete (CRUD). SQL database frameworks are quickly developed and easily maintained compared to more powerful tools like MS LINQ. Since this system is a prototype, we propose to use the simpler and faster methods. Using SQL Server also maintains compatibility across all levels of the infrastructure that use Microsoft tools. Data in the

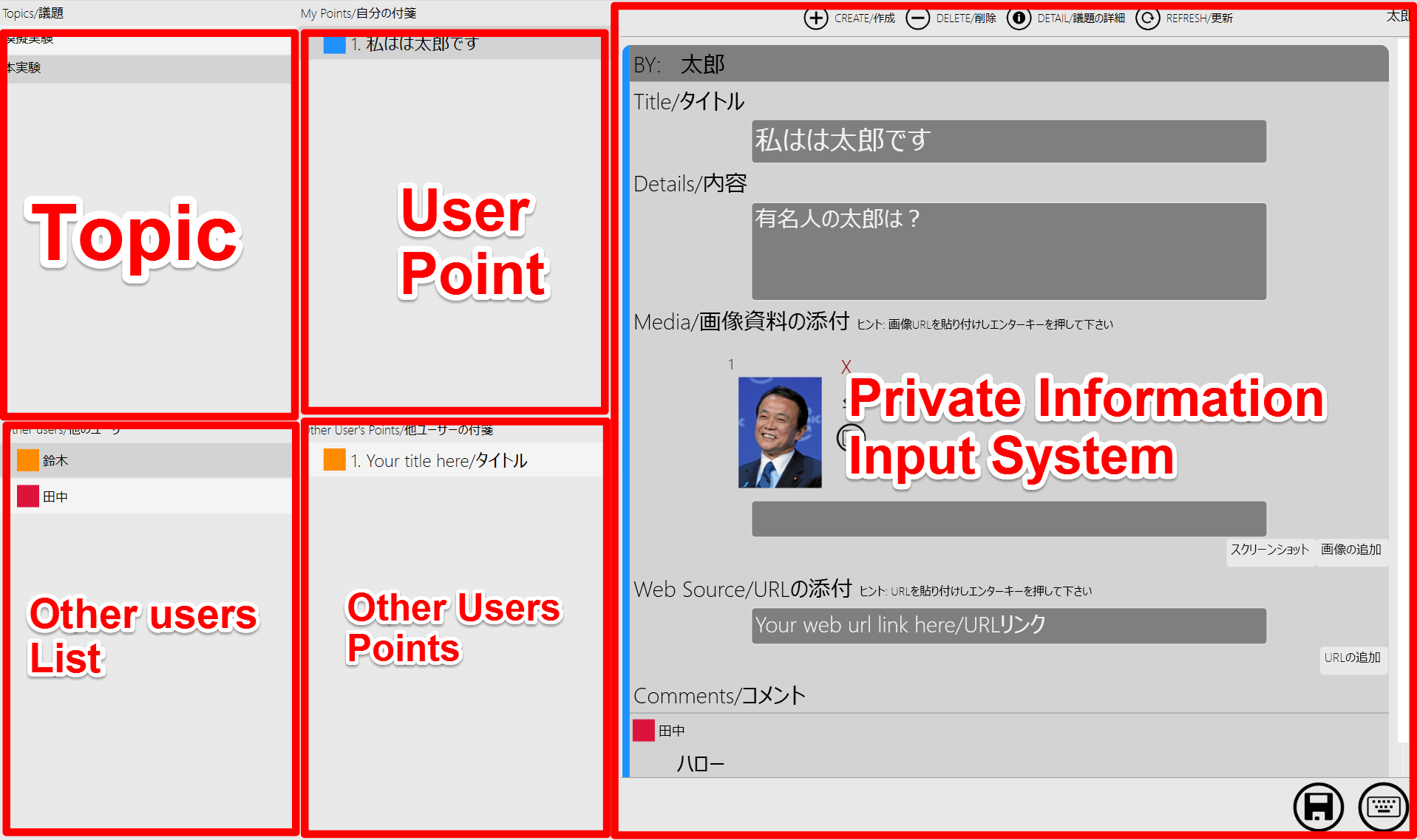


Figure 3. Private Space User Interface

database can be easily created, read, updated, and deleted from the client end of the system, and the network socket server can access and synchronize these updates across all users.

*Server Infrastructure*

The server performs two important functions in DADS: storing the database and its structure, and manipulating the database synchronously across all client instances using a network socket service. The database is stored using the XML file format, which is web ready and highly portable between programs. The network socket service used for DADS is the Photon Engine, developed by Exit Games [Exi, ]. We use Photon Server SDK in the server application to automatically update changes between clients and servers, for notification and synchronization between client displays. Rather than a traditional system, we chose Photon Engine for its ability to instantly notify all other parties in a distributed group of clients. Data exposure is managed by ASP.net and Windows Communication Foundation data services (WCF). WCF data services exposes this data through the Open Data (OData) protocol, making it easy for DADS to provide data to other platforms such as Android, iOS, or a web portal. At present the data services integration is peripheral to the performance of the system, but this cross-platform flexibility lays the foundation for future development and extension, for example into tablet applications.

# Distributed Common Interactive Space

The way DADS is constructed has two larger goals: to have higher usability, and to be more efficient than analog methods of collaborative affinity diagram creation. The technical details of the client interface, database, and server system are only useful to the degree that they improve our users’ experience and make it easier to accomplish the tasks involved in creating a collaborative affinity diagram. The following section discusses the method by which we compared our system to the analog version of the same activity, to see which system is more usable and more efficient.

# EXPERIMENT METHODS

While our previous research[Widjaja et al., 2013] focused on validating the Discusys system and its basic usability, the current paper explores usability with a more accurate survey

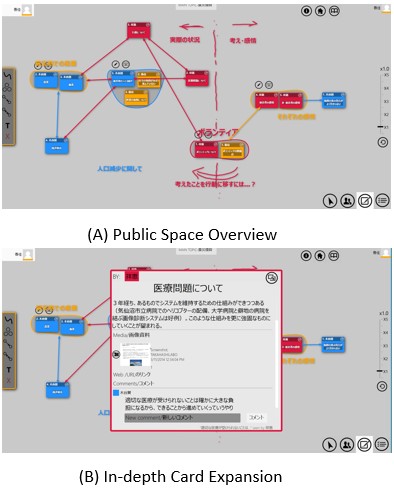


Figure 4. (A) Screenshot of common interactive Space interface with groups and links (B) Card Expansion: double tap gesture expands the selected card to display in-depth information including details, images and comments

and analysis of performance. This experiment tests the hypotheses we have explained above, concerning content creation and navigation, attaching sources, presentation and explanation, comments, and flexibility. We also explore several correlations that suggest interesting relationships between usability reports and users’ performance with the system. To strengthen our claims, we have increased the number of discussion participants per group from 2 to 3 in order to simulate a more realistic discussion. We have also tried to standardize the data output for more stable results by structuring the discussion using recommended topics and a modified Nominal Groups Task sequence.

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:

1. Nuclear Energy - Discuss your opinion about the current Nuclear Energy policy in Tohoku
2. 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. The U-shaped seating design in the Digital condition 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. 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 interactive 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.

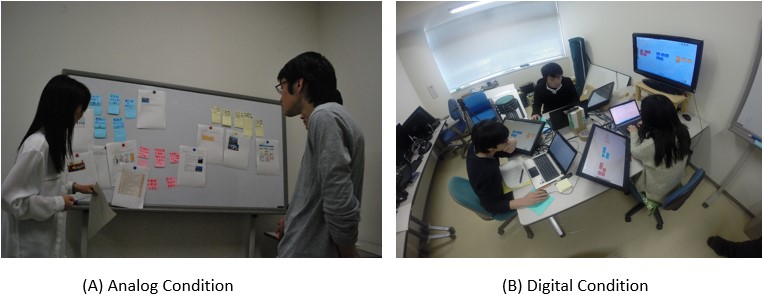


Figure 5. (A) Analog Condition: using sticky note and white board (B) Digital Condition using DADS with auxiliary multi-touch monitors.

# INSTRUMENTS AND METRICS

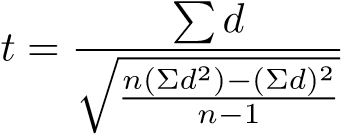
We operationalize usability in three ways: a usability survey administered to participants, a more general System Usability Score, and several behavioral performance metrics. Our analyses determine which of the two methods is more preferred by users and whether DADS supports users in exchanging and organizing 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.

We chose p = 0.05 as our threshold for significance for the paired t-tests, reflecting a value of *α* = 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 for measuring usability and affective results, 2) Performance Results for checking efficiency 3) Correlation Data result to see the correlation between the usability and the performance. the first part we discuss the results of the survey with the focus on 1) content creation and Presentation 2) Exchanging Comments 3) Navigating, Understanding and Affinity Diagram and finally the 4) 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

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 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 |  | |

*Content creation and presentation*

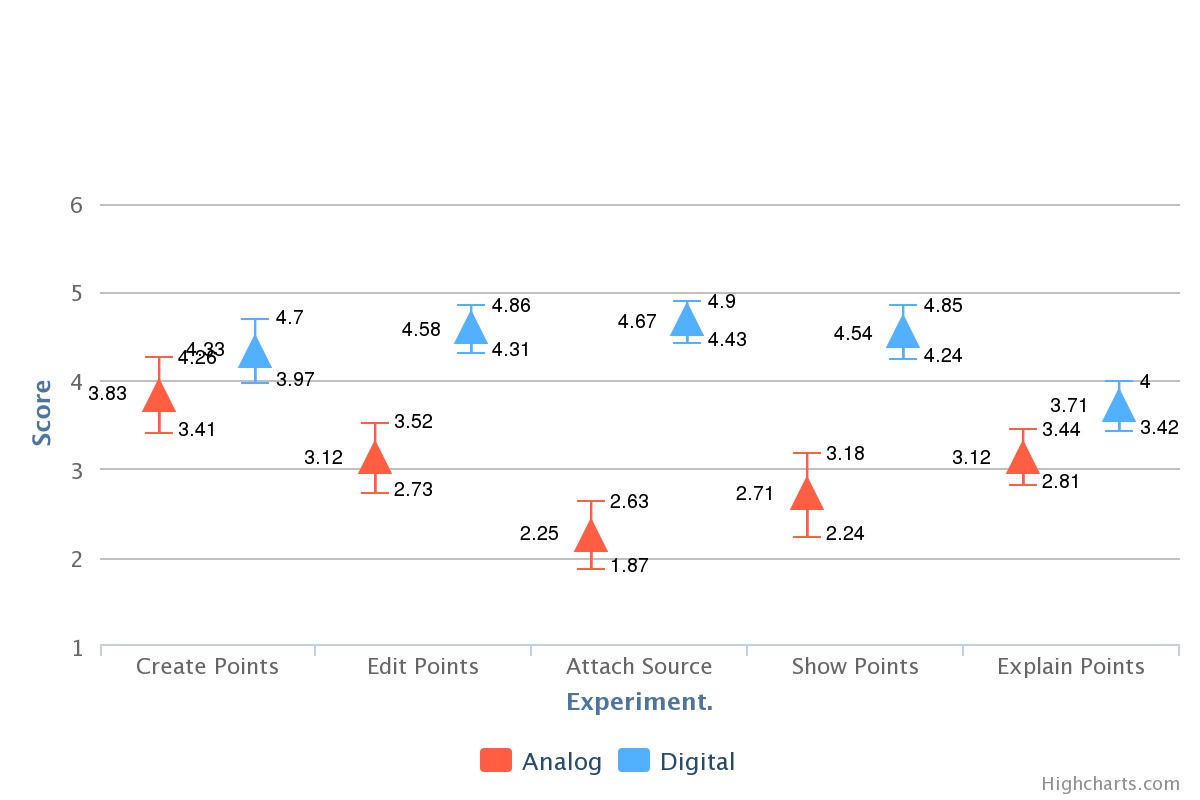


Figure 6. Usability Survey T-test Results

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.

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 (0.95) p *<*0.05). Participants also found that editing in digital environment is significantly easier (M = 4.58 (0.65)) than the same process in the Analog condition (M = 3.12 (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=4.67(SD =0.56)) compared to Analog ( M=2.25, (SD=0.90), p*<*0.01). 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=4.54, SD=0.) compared to Analog (M=2.71, (SD=1.12) P*<*0.01)). Users also report that it is easier to explain ideas in the Digital environment (M=3.71, SD=0.69) compared to Analog (M=3.12, SD=0.74, P *<*0.05). 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.

*Organizing Comments*

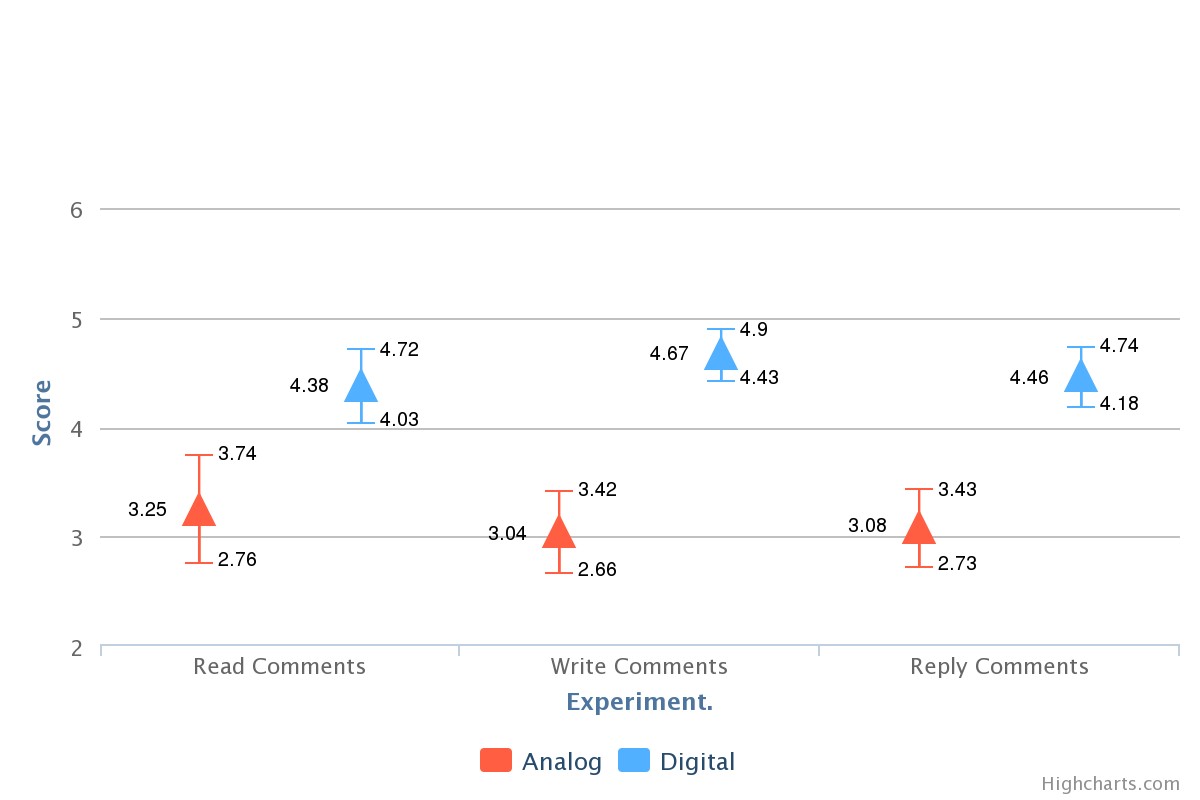


Figure 7. Analog and Digital T.test result for commenting

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 the experiment report a significant difference between analog ( M=3.25, SD= 1.15) and Digital (M=4.38, SD= 0.88, p *<*0.01). Subjects also reported that it is easier to write comments in the Digital system (M=4.67, SD=0.56) compared to writing manually (M=3.04, SD=0.91 *<*0.01). Finally, when evaluating the notification system for replying to comments, users rate the Digital format higher (M=4.46, SD= 0.66) than Analog (M=3.08, SD= 0.83) suggesting that it is easier to reply to comments using the digital interface.

*Navigating, Understanding and Flexibility*

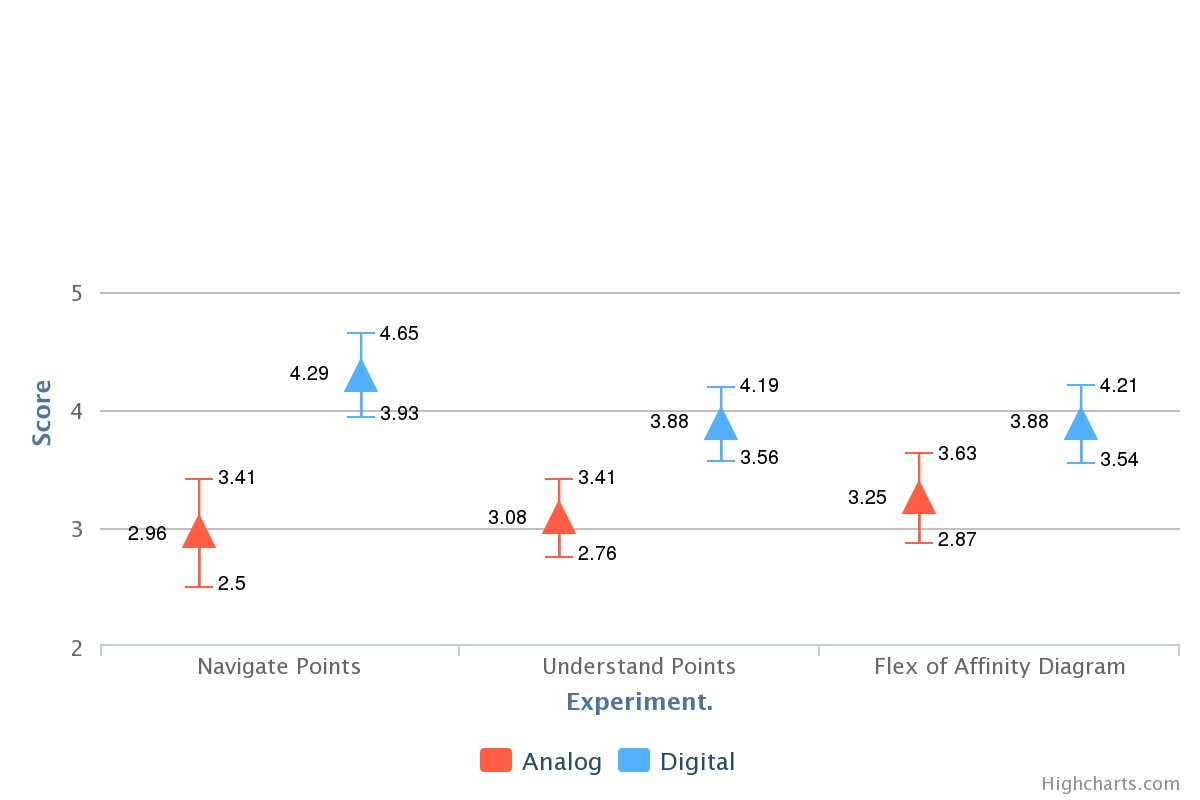


Figure 8. (A) Analog and Digital t-test result for navigation

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=4.29, SD=0.86) compared to Analog (M=2.96, SD=1.08, 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=3.88, SD=0.8), compared to Analog format (M=3.08, SD=0.78, p *<*0.01). Collaborating on the affinity diagram was more flexible using the digital system (M = 3.88 (0.8)) than the analog system (M = 3.25(0.9), p *<*0.05), which conclude that according to the experiment, users felt slightly more flexible organizing cards to form affinity diagram in Digital conditions compared to analog conditions.

*Affective Metrics*

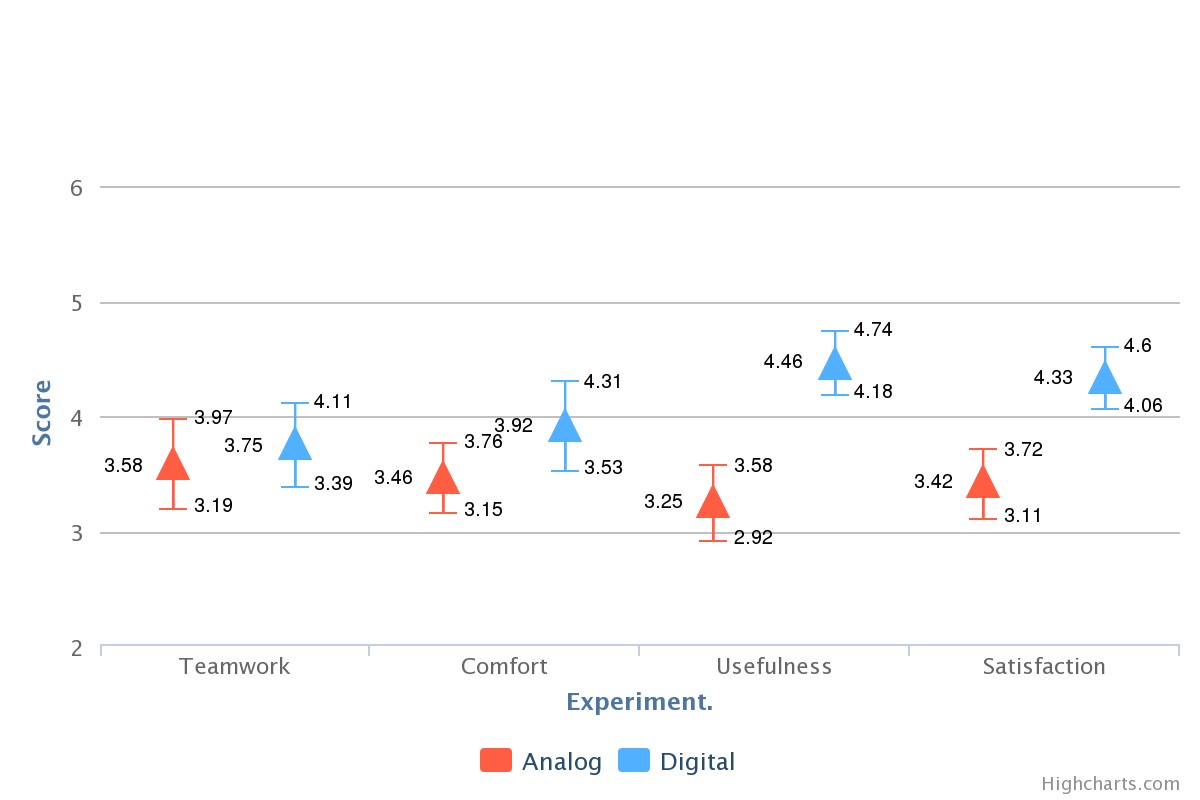


Figure 9. Analog and Digital t-test result for performance measures

We also asked users several questions that reflected their general feelings about the system: how useful it was compared 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 = 4.46 (0.64), Analog M = 3.27 (0.96), p *<*0.01), and they also report that they feel slightly more comfortable in the Digital system (M = 3.92(0.93)) than the Analog system (M = 3.46, (0.72), p *<*0.05) . Users also reported to be more satisfied with the conclusion of the affinity diagram from the digital process (M = 4.20 (0.68)) compared with the Analog process (M = 3.47 (1.06), p *<*0.01). Finally, we discovered during the experiment, while rating their perspective teamwork, we discover that there is no statistical difference between the rating of teamwork in Digital M = 3.87 (0.83) and Analog M = 3.53 (1.06), p = 0.31). With some of participants are mixed between which of the two conditions promote more cooperation or teamwork. We felt that this is due to the nature of distributed screen where users are not able to properly coordinate the creation of affinity diagram. Thus as a result, the experiment shows that users are not able to differentiate which of two promote collaboration more.

# Performance Metrics

|  |  |  |  |
| --- | --- | --- | --- |
|  | 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 |
| Time for Affinity Diagram (minutes) | 7.11(2.11) | 15.07(11.10) | *<*0.01 |

Table 2. Performance Metrics Results

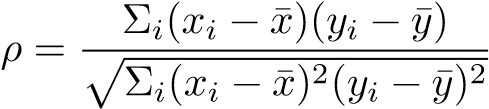
We coded participants’ behaviors in both the Analog and Digital conditions, counting the number of times cards were moved and re-grouped, as well as the number of supporting attachments users made to their points. Self-reports from our usability survey are supported by data from users’ behavior. For 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.

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 which means that users engage in more activities in Digital compared to Analog. In addition, users spent more time as a group in the Digital condition at a mean of 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). The result do not shows that it is more time efficient in both conditions as both average almost the same time together, however we found out that users spend almost longer in the digital conditions. When we probe further about the longer time taken, subjects felt more flexible with the digital system and may have been more inclined to extend their discussions and explore different more possibilities in 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.

# Correlation Analysis

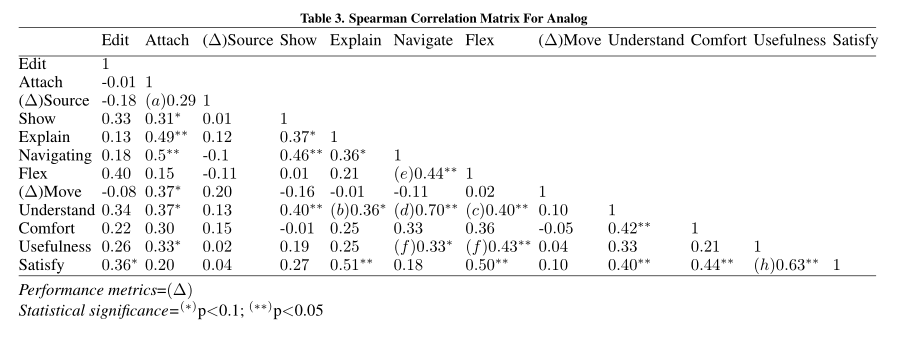
We present several correlations that explore the relationships between different survey metrics, and between these metrics and user performance. These correlations enrich our understanding of the relationship between user experience and user behavior in three separate areas: the content creation system, 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.

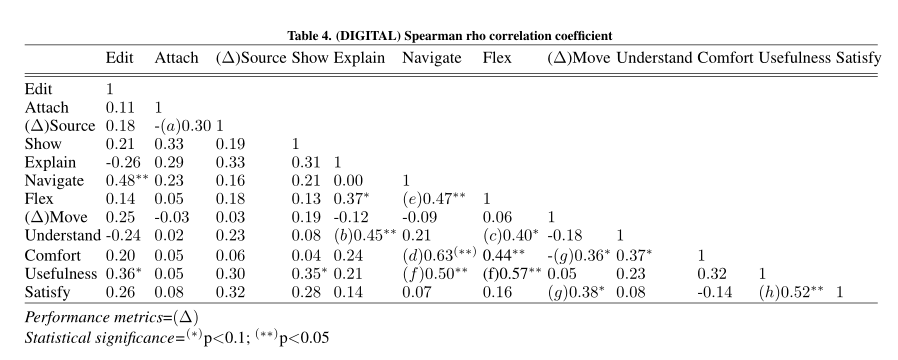
Correlations allow us to see whether a rise or fall in one factor impacts another factor that we are measuring. For example, if users score our system high on the ease of making attachments, does this mean that they also make high numbers of attachments? A correlation coefficient can tell us whether 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 *rs* is calculated as follows:



Statistical significance for Spearman’s *rs* , 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 *rs* 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.





1. 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.
2. 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 (*rs* = 0.45, p=*<*0.05). The evidence for this relationship is present, but less clear in Analog (*rs* = 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.
3. 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 (*rs* = 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.
4. Ease of navigation is also strongly correlated with under-standing in the Analog condition (*rs* = 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 (*rs* = 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.
5. We also confirmed that ease of navigation between discussion points and flexibility are correlated in both Analog ((*rs* = 0.44, p=*<*0.05) and Digital conditions (*rs* = 0.47, p=*<*0.05). This may indicate that navigation and flexibility address similar functions or are mutually influencing.
6. Ease of navigation is highly correlated with usefulness for Digital users (*rs* = 0.49, p=*<*0.05), while for Analog users the correlation is still positive, but not as strong (*rs* = 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 (*rs* = 0.57, p=*<*0.05) and Analog at (*rs* = 0.40, p=*<*0.05). This helps us define flexibility as one of the key elements of usefulness, and thus closely related to usability.
7. 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(*rs* = -0.36, p=*<*0.1) but positively correlated with the level of satisfaction (*rs* = 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.

h) Our last correlation shows that Level of Usefulness and Level of Satisfaction are highly correlated for both Analog ((*rs* = 0.63, p=*<*0.05) and Digital users (*rs* = 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:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. 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= ∑ (*a* −1)+(5− *b*)+(*c* −1)+(5− *d*)+(*e* −1)+

(5− *f*)+(*g* −1)+(5− *h*)+(*i* −1)+(5− *j*)∗2*.*5

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.

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 |

Based on the 24 subject which answer all the 10 questions, we first calculated the cronbach alpha which is a coefficient of internal consistency is 0.760.76 which is a good consistency between the various respondents. We also calculate the 10 questions results based on the above formula to get 3 objective scores for the digital system: Usability Score, Learnability Score, and finally the overall System Usability Score (SUS) score[Brooke, 1996]. Based on the results, we report that usability score of the total respondent was 78.0, however the score for learnability is 58.3. We believed that users are still not accustomed to the setup for the first time and report the need for more time to familiarize themselves with the system. Finally, our overall score for the system usability scale (SUS)was 74.1, Comparing the industry standard of 68[Lewis and Sauro, 2009], we can report that the system has a very high usability score and should be considered a strong potential alternative to traditional methods in supporting groups in collaborative affinity diagram activities.

# 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 users’ behavior in the analog system is less varied, reflecting their familiarity with pen-and-paper collaborative work. Our research has clarified the usability and efficiency of the design of DADS, and our correlation analysis suggests new hypotheses that can inspire 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.

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