Measuring Effects of Private and Shared Displays in Small-Group Knowledge Sharing Processes

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ABSTRACT

Knowledge sharing is important in every team or organization. Various tools are frequently used in meetings to support knowledge sharing, ranging from pen-and-paper to whiteboards and other shared workspaces. This paper reports on a user study that investigated how private and shared displays affect knowledge sharing processes in co-located meetings. Three setups were compared in a hidden-profile experiment: a distributed system providing a shared display and laptops (Note&Share), a regular whiteboard and pen-and-paper. The results show several advantages of the distributed system. For example, the group was more confident in the solution when using Note&Share. Furthermore the number of shared arguments was significantly closer to the correct number, which suggests that misunderstandings occurred less frequently. Finally some interesting effects were observed, which we claim to be connected to the availability of pen-and-paper in all conditions. Therefore, we discuss the observed effects as well as general lessons learned from this experiment.

Author Keywords

Knowledge sharing, multi-display environment, hidden profile experiment, mind map

ACM Classification Keywords

H.2.3 [Information Interfaces and Presentation]: Group and Organization Interfaces---Computer-supported cooperative work.

INTRODUCTION

Knowledge sharing is crucial because people rely on each other "[…] *for information, problem solving and to learn how to do their work*" [3]. In any meeting that strives for a convergence of multiple people's knowledge, opinions or ideas, there is a potential problem because collaborators often share their knowledge ineffectively [11]. Certain information that is held by only one group member is likely to be ignored and not regarded during decision making [9]. This effect may be countervailed by a protocol that tells each group member to first individually note down their knowledge or vision (prior to or at the beginning of the meeting) and later share them with the group [10]. We have built a distributed application called *Note&Share*, which is designed to facilitate such a protocol. It consists of a personal workspace (laptop) for each group member in addition to a shared workspace (smartboard) for the collaborative phase. The laptops can be used to note down keywords and to send them to the smartboard with a simple drag-and-drop gesture. A moderator can then arrange the keywords in a mindmap on the touch-sensitive wall display.

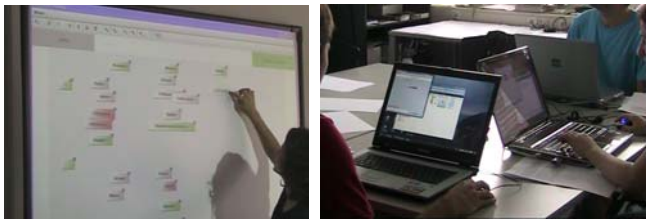

Figure 1. Note&Share Smartboard (left) and Laptops (right)

A study was conducted to investigate how private and shared (non-technological and digital) displays affect knowledge sharing processes in meeting situations. For that purpose Note&Share, which provides a shared as well as personal displays, was compared to a regular dry-erase whiteboard as well as pen-and-paper. To be able to measure the degree to which information was shared, a hidden profile experiment was chosen, in which information pooling is required to find the best solution [9].

RELATED WORK

This work combines ideas from different research directions. On the one hand, there is related work on knowledge sharing, focusing mainly on distributed teams and knowledge transfer in organizations, e.g. [3]. Also, representations such as mind maps have been applied in knowledge modeling and sharing [2], however, not in co-located groups. On the other hand, there are various multi-display environments (MDE), such as the WeSpace [12] or IMPROMPTU [1]. Most of them aim at application sharing, but none of them specifically target at knowledge sharing.

In terms of the effects of multi-user applications on collaborative processes, different aspects have been examined in previous studies. Most studies focus on one shareable user interface such as an interactive tabletop display and analyze

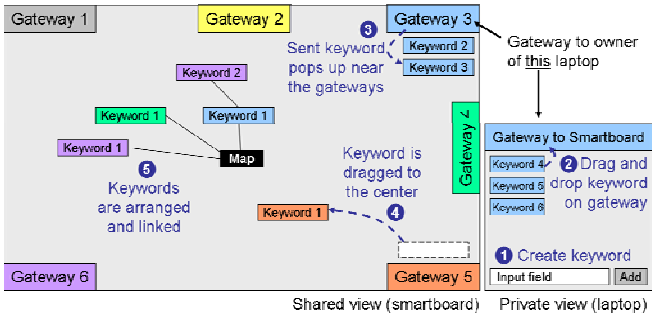

Figure 2. Interaction with Note&Share (Schematically)

e.g. how the size of a tabletop display influences social interaction [8] or how shared vs. replicated controls affect collaboration [5]. Nacenta et al. examined the effects of interaction techniques, such as *Pick&Drop* or *RadarView* [6]. Although the interaction techniques can be used in multi-display environments, the study was also conducted using one tabletop. Rogers et al. compared the number of role switches and explored ideas as well as awareness in horizontal vs. tabletop displays, but again only one display was used in each condition [7]. However, such effects have not been investigated in MDEs. Also (with the exception of [7]), pen and paper is rarely used in these studies.

NOTE&SHARE APPLICATION

Note&Share is designed to support effective knowledge sharing where the knowledge of all participants is equally taken into account. It consists of one personal laptop for each individual of the group and a wall-mounted, interactive smartboard. Each laptop stores the knowledge of its respective owner and can therefore be used prior to or during a discussion. The smartboard serves as a shared, touch-sensitive display that supports knowledge exchange.

Clients running on all laptops are connected to the smartboard via wireless LAN to allow an easy information exchange. Information transfer is initiated using the Gateway Interaction Technique [4]. Each client window has a "gateway" bar on the top edge, which represents the shared display. After creating keywords that represent relevant knowledge (step 1 in Figure 2), they can be dragged onto the gateway in order to transfer it to the smartboard. Using the same interaction technique, keywords can be sent back to the laptops using the smartboard's gateways, which are distributed along the edges (see Figure 2). Keywords sent by a discussion member pop up next to the corresponding gateway. The moderator operating the smartboard can arrange the keywords in the center and, if needed, create a mind map to visualize and structure the shared knowledge.

EVALUATION

We conducted a study to identify the effects of shared as well as personal displays. The following research questions were investigated: (1) To what extent does the availability of private and shared displays affect knowledge sharing processes (i.e., amount of shared information, time)? (2) To what extent does the availability of private and shared displays affect the quality of decisions?

Experiment Design

In the study three different tools were compared regarding knowledge sharing processes and quality of decisions: Note&Share, a regular dry-erase whiteboard and pen-and-paper. A within-subject design was chosen, i.e. eight groups of four used all three tools in a counterbalanced order. All of the 32 participants were university students, 14 female and 18 male. 26 of them were between 19 and 25 years old, the others between 26 and 30.

Task

For the purpose of this study, three hidden profile tasks were created. In hidden profile experiments, each person is given a different subset of information on several candidates [9]. In this experiment the tasks were: Finding the best (1) job candidate, (2) holiday destination and (3) wall paint for a nursery. The cases were randomly assigned to the conditions. The key property is that the reader of a single case description would choose the wrong candidate because only a subset of information is considered. Only if all aspects are taken into account the best candidate is found, which requires information exchange. Each group of four had to solve all of the three hidden profile cases. Three group members, the so-called 'analysts', were given the different case descriptions. The fourth group member was assigned the role of a moderator. Moderators did not get case descriptions but were in charge of consolidating all information. After the case descriptions were handed out, the analysts were given as much time as they needed to read it and create keywords for all pro and con arguments of all candidates, using their laptops (Figure 2). Afterwards the moderator was in charge of a discussion, in which the group had to agree on one candidate. During the discussion, arguments were sent to the smartboard and mostly arranged in table form, which is better suited for counting pro and con arguments than a mindmap.

Conditions

The group was provided with different tools: pen-and-paper only (C1), a regular dry-erase whiteboard (C2) and Note&Share (C3). In all conditions case descriptions were handed out on paper. In C1 no additional tools were provided. In C2 the moderator was allowed to write and draw on a whiteboard. In C3 the analysts had to note down keywords on laptops and later send them to the smartboard, which was controlled by the moderator. Thus, a shared representation of the group's knowledge only existed in C2 and C3. Working a case took between six and 20 minutes (13 minutes on average) per tool.

Hypotheses

The first hypothesis was that a shared representation of the group's knowledge (in C2 and C3) facilitates knowledge sharing (H1), which therefore increases the probability that the best solution is found (H2). Second, Note&Share forces analysts to find a good representation (keywords) for their knowledge on their private displays prior to delivering it verbally. Therefore we hypothesize that analysts need less time to deliver arguments when using Note&Share com-

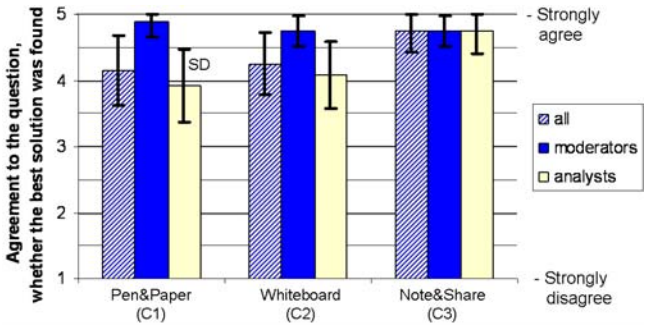

Figure 3. Participants' confidence in the quality of the result

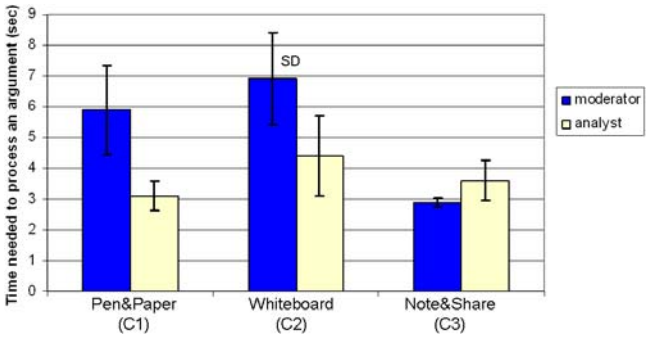

Figure 4. Average time needed per argument by roles

pared to both other conditions (H3). On the contrary, in the Note&Share condition, moderators receive keywords and only need to arrange them. This means that moderators need less time to process delivered arguments (H4).

RESULTS AND DISCUSSION

Quality of collaboration and outcome

In order to assess the quality of the collaboration, the number of shared arguments and the final result were recorded. The total number of arguments in each hidden profile case was 15, some being mentioned in only one case description, others being redundant. Thus, if more than 15 arguments were shared redundancies were not identified while less than 15 arguments equals information loss. Using pen-and-paper the mean number of shared arguments was 18.5 (SD 1.87), 17.4 (SD 4.16) in the whiteboard and 16.0 (SD 1.55) in the Note&Share condition. Consequently, the main problem was identifying redundant arguments (not information loss as hypothesized), but Note&Share still was closer to the optimum than the other two conditions, which suggests that misunderstandings occurred less frequently.

Looking at the final outcome, the best solution was found in 19 of 24 cases. Out of the other five cases, three were in the pen-and-paper condition and one in each of the other conditions. Three times the wrong conclusion was made in the group's first case, twice in the last case. A χ^2-Test revealed no significant differences between the tools regarding the amount of best solutions. The reason for the wrong outcome was either unidentified redundancies (occurred three times) and/or groups started to weigh arguments according to their personal judgment instead of comparing the number of pro and con arguments (twice). Information loss, which is the effect we expected in the first place, only occurred once. Interestingly, unidentified argument redundancies were also quite common in cases where the final result was correct. Only in five cases the number of shared arguments was correct, four of them were in the Note&Share condition.

Although these results strongly plead for a multi-display environment like Note&Share, they do not confirm H1 and H2, which hypothesized that Note&Share and the whiteboard both facilitate knowledge sharing better than pen-and-paper. We claim that the main reason is the "*moderator effect*" we have observed in the pen-and-paper condition: As pen and paper were available, most moderators consolidated verbalized information on a sheet of paper in a similar way as they did on the whiteboard. Thereby, the paper served as the moderator's private information pool, which helped them in preventing information loss. However, as analysts could not read the moderator's notes they had less confidence in the quality of the solution (see Figure 3).

Role-Specific Cognitive Load and Time Requirements

For the verification of H3 and H4, the video recording of the discussion phase was analyzed to the split second. For each delivered argument the time analysts needed to deliver an argument was measured as well as the time moderators needed to process it. Figure 4 shows the means and standard deviations for analysts and moderators in each condition. Using Note&Share there was a significant time saving for the moderator compared to the whiteboard, $F(1, 4) = 29.00$; $p < .05$; partial $\eta^2 = .88$, which supports H4. However, there is no significant difference in the time needed by the analyst. H3 could therefore not be confirmed by this experiment. A possible explanation is, again, that in the conditions where no laptop was provided, the analysts took notes on paper, which had a similar effect as creating keywords using the laptop.

SUBJECTIVE EVALUATION

In a post-questionnaire we asked participants about their preferences for the three tools and their understanding of different effects that occurred while using them. When asked whether they thought the best solution was found (cf. Figure 3) on a 5 point Likert scale, a within participants analysis of variance showed a significant effect for the tool, $F(2, 62) = 5.92$; $p < .05$; partial $\eta^2 = .16$. A Bonferroni post hoc test revealed that the agreement was significantly higher for Note&Share compared to whiteboard ($p=.004$) and pen-and-paper ($p=.009$). Interestingly, the moderators rated the pen-and-paper condition significantly higher ($p=.001$) than the analysts. This may be due to moderators relying on their personal notes, which analysts could neither see nor control.

Furthermore, the kind of tool had a significant effect on the overview of all arguments, $F(2, 62) = 9.03$; $p < .05$; partial $\eta^2 = .23$. According to the post hoc test learners rated the overview of shared arguments significantly better in the Note&Share condition as compared to whiteboard ($p=.013$) and pen-and-paper condition ($p=.001$). Finally, there was a

significant effect regarding the question, whether information was shared effectively, $F(2,62) = 4.20$; $p < .05$; partial $\eta^2 = .12$. Both the whiteboard (p=.021) and Note&Share (p=.03) were rated significantly better than pen-and-paper.

Finally, participants were asked to rank which tool best fulfilled different usability criteria. The whiteboard was considered as being the easiest to use (first-ranked by 48%), followed by Note&Share (36%) and pen-and-paper (16%). However, Note&Share was considered the most helpful (best-ranked by 65%) followed by the whiteboard (35%). It was also by far the tool that was liked best (first-ranked by 84%, the other 16% voted for the whiteboard). A Friedman-Test for related samples showed a significant difference between the ranks of the three tools, N=32, χ^2=40.11, df=2, $p < .001$, two-tailed. A post hoc Wilcoxon-Test revealed significant differences between whiteboard and pen-and-paper, N=32, Z=4.51, p<.001, as well as between Note&Share and pen-and-paper, N=32, Z=5.015, p<.001.

CONCLUSION AND FUTURE WORK

Multi-display environments with shared and private displays have the potential to facilitate knowledge sharing. A hidden profile experiment was conducted to compare such a system to two other (non-technological) displays that are often used in meetings: a dry-erase whiteboard and pen-and-paper. The experiment showed that the number of shared arguments was closer to the number of the arguments in the hidden profile case. Furthermore, analysts had significantly more confidence in the quality of the results.

To us similarly important as these findings are the lessons learned from conducting this study. Although the intention of our experiment was having a control condition, in which no displays were provided, the availability of pen-and-paper (as an everyday auxiliary tool) had a similar effect as it had been achieved by a personal display. This problem could apply to many studies investigating how displays affect collaborative processes. In ideal control conditions pen-and-paper is not available as it substitutes a display in some ways. This would, however, result in a very artificial collaborative setting, in which participants would be asked to discuss a case while being forbidden to take any notes. As this is a severe constraint to how people are used to work, it is obvious that the group would perform very poorly. Thus, we settled for a more authentic (yet less clean) control condition. Consequently, it was difficult to foresee how participants would behave and our initial hypotheses could only partly be confirmed. The experiment still provided some interesting findings and we argue that – although not ideal – the better design alternative was chosen for this experiment.

In the future, we plan to conduct a follow-up study to verify the moderator effect, which was observed in this experiment. Our hypothesis is that by assigning the role of a moderator to one group member, knowledge sharing can be enhanced in the same way as by using a shared display. We also plan to examine whether the generation of keywords has a positive effect on the structure of spoken arguments.

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