User experience in using surface computing for collaborative decision making

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Abstract

Purpose – This paper aims to report work regarding the design, development and evaluation of a surface computing application to support collaborative decision making. The domain-independent application, the so-called Ideas Mapping, builds on the principle of affinity diagramming to allow participants to analyze a problem and brainstorm around possible solutions, while they actively construct a consensus artifact – a taxonomy of their ideas.

Design/methodology/approach – Ideas Mapping was designed using a user-centred approach. During idea generation, Ideas Mapping replicates physical post-it notes on a multi-touch tabletop. Additional functionality supports student collaboration and interaction around the organization of ideas into thematic categories associated with the problem at hand. The tool was evaluated in two studies using quantitative and qualitative data.

Findings – The paper reports on the functionality and user experience while interacting with the application. The paper also reports initial findings regarding the affordances of surface computing for collaborative decision making.

Originality/value – The studies reported give insides regarding the affordances of multi-touch tabletops to support collaborative decision making. Information regarding the user experience in using such applications is reported.

Keywords Communication technologies, Multimedia

Paper type Research paper

Introduction

A multi-touch interactive tabletop can support collaboration, allowing different patterns of turn taking, negotiation and interaction (Harris *et al.*, 2009). In this paper we report the design, development and evaluation of a surface computing application that supports idea generation, collaborative decision making and group artifact construction. The paper starts by covering related research literature and continues with the description of the design and development of Ideas Mapping and its use in two studies aiming to understand the affordances of surface computing for collaborative decision making. The paper concludes with a discussion of the key findings and makes suggestions to researchers and practitioners.

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Existing knowledge

The work reported in this paper draws from literature in the areas of human computer interaction (HCI) methods (affinity diagramming), technology-enhanced learning and multi-touch interactive tabletops. The current state of the art in these areas is briefly summarized in this section.

Affinity diagramming

HCI techniques exist to facilitate discussion in groups and to extract ideas from users' initial conceptual models. For example, the Kawakita Jiro diagrammatic method (Kawakita, 1975), also known as affinity diagramming, is a team-based knowledge elicitation technique. It is used for grouping information into categorical domains (Nielsen, 1994) and bears similarities to open card sorting. Users write down items of knowledge or descriptions on sticky notes and then organize the notes into groups before creating group headings. These methods are useful to HCI specialists as techniques for creating and analyzing categorizations of knowledge and are considered among the foremost usability methods for investigating a user's (and groups of users') mental model of an information space (Martin, 1999). In affinity diagramming, the method is enforced in teams usually working on a shared whiteboard or large piece of paper. They are encouraged to communicate their reasoning verbally; thus, collaborative team decisions upon consensus lead to category cluster formation (Beyer and Holtzblatt, 1998).

Multi-touch interactive tabletops

Multi-touch surfaces have the ability to recognize multiple points of contact by one or multiple users. This feature allows for new forms of interaction especially in regards to zooming, rotating or moving objects on the interactive surface. Based on preliminary evidence from the education and computer-science literature, Higgins *et al.* (2011) provide a review of the technological characteristics of multi-touch interactive tabletops and their pedagogical affordances. Overall, as pointed out by Higgins *et al.* (2011), most of what we know in this area concerns technical issues related to interaction of users with the technology, but we know little about the use and value of multi-touch tabletops in collaborative learning situations within formal educational settings. Below we summarize some recent empirical evidence related to multi-touch tabletops and learning.

Multi-touch tabletops have been used with disabled user groups to promote development of social skills. SIDES, for example, is a four-player cooperative computer game designed to support adolescents with Asperger's syndrome to practice social skills and effective group work during their group therapy sessions (Piper *et al.*, 2006). SIDES provided an engaging experience for this audience who remained engaged in the activity the entire time and learned from the activity (unlike typical behavior of this population) (Piper *et al.*, 2006). Similarly, StoryTable was initially designed to support children's storytelling activity in groups (Cappelletti *et al.*, 2004); evaluation of StoryTable showed that it enforced cooperation between children during the storytelling activity, by allowing simultaneous work on different tasks, while forcing them to perform crucial operations together in order to progress (Cappelletti *et al.*, 2004). Moreover, StoryTable has been used to facilitate collaboration and social interaction for children with autistic spectrum disorder with positive effects (Gal *et al.*, 2009).

In some other work, multi-touch tabletops have been studied for their added benefits compared to single-touch tabletops. Harris *et al.* (2009) contrasted groups of children in multi-touch and single-touch conditions and found that children talked more about the task in the multi-touch condition while in the single-touch condition they talked more about turn taking. Furthermore, the technology is considered engaging. For example, the overall (perceived) usefulness and benefit of using interactive tabletops in collaboration contexts was assessed in a recent experiment by Buisine *et al.* (2012) with 80 participants. That study showed that groups in the tabletop condition had improved subjective experience and increased motivation to engage in the task.

With regards to using tabletops in formal learning settings, a series of studies are currently being conducted as part of the SynergyNet project (Higgins *et al.*, 2011). SynergyNet focuses on how a network of tabletops can best support collaboration within small groups, while undertaking the development of curricula and tabletop applications for classroom integration (Higgins *et al.*, 2011). A recent SynergyNet study contrasted groups of children in multi-touch and paper-based conditions to examine the differences in their collaborative learning strategies (Higgins *et al.*, 2011). The authors found that student groups in the multi-touch condition maintained better joint attention on the task compared to groups in the paper-based condition. Another recent SynergyNet study examined NumberNet, a tool designed to promote within and between group collaboration in a mathematics classroom using a network of tabletops (Hatch *et al.*, 2011). In this study, pilot results from 32 students showed significant knowledge gains from pre to post testing.

Design methodology

We adopted a strongly user-centered approach, emphasizing the engagement of students and instructors in all phases of the design process. Four university students and three instructors were involved, contributing to design elements of the application.

First, through low-fidelity paper-based prototypes, we simulated a collaborative activity with four students around a (turned-off) tabletop using paper and pencil. The scenario involved “the creation of a computer games industry in Cyprus and the factors involved”. First, students generated ideas individually for 10 minutes. They wrote a (physical) post-it note for each new idea. Next, the ideas appeared one-by-one on the table and became subject to discussion, after a brief explanation from their originator, in an effort to categorize them in thematic units. Students revisited and changed ideas, rejected less promising ones, and generated new ideas during a collaborative decision making process leading to a thematic categorization. Finally, the activity concluded with a consensus on the main factors (i.e. resulting thematic categories) involved in the creation of a computer games industry in Cyprus. After the completion of the activity, instructors (who observed and kept records of all interactions during the activity) and students discussed the potential surface computing application and contributed to elements of the design from their own viewpoints.

Following the low-fidelity design discussions and analysis of user needs, a prototype Beta version application was developed in Action Script 3.0, for a multi-touch tabletop, the MagixTable. The application, so-called Ideas Mapping, was designed to be domain-independent with a mild learnability curve. Our participants were called back to collaborate on different scenarios using Ideas Mapping and to provide feedback on its user experience and further suggestions for improvement. Evaluation sessions took place in a fully equipped usability lab and all sessions were video recorded and analyzed. Ideas Mapping was optimized and finalized in three major iterative cycles of design, development and evaluation.

Overview of the application

Overall, Ideas Mapping is designed to support idea generation, collaborative decision making and group artifact construction. The application builds on the principle of affinity diagramming to allow participants to analyze a problem and brainstorm around possible solutions while they actively construct a consensus artifact; namely, a taxonomy of their ideas (Plates 1-3). In a sense, Ideas Mapping aims to make the affinity diagramming technique more collaborative; by allowing for an extension sorting activity, it provides a way for participants to negotiate around an emerging group artifact and make sense of challenging problems.

Plate 1.
Participants interacting with Ideas Mapping

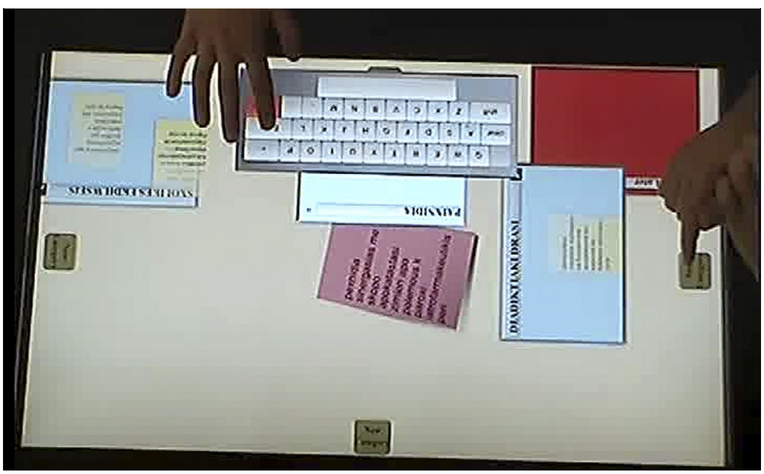

Plate 2.
Categorization of ideas it in thematic units

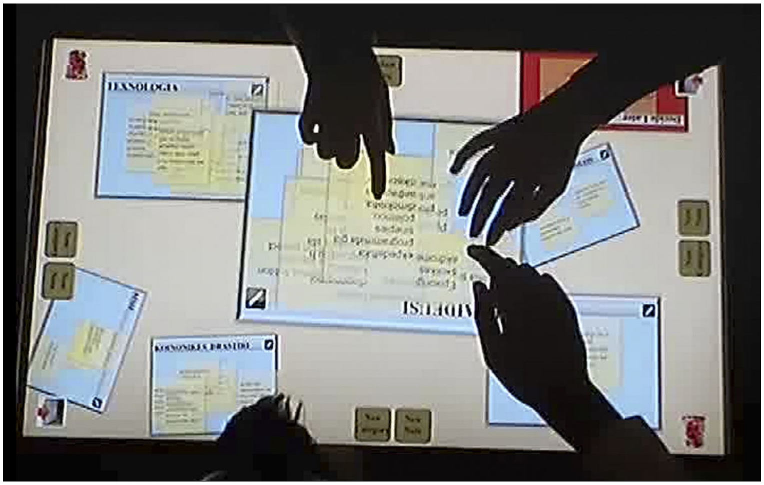

Plate 3.
Consensus on a group artifact

This is done in three stages:

Stage 1. With a scenario at hand, each collaborator generates new ideas. Ideas are typed into a web application (producing an XML file associated with Ideas Mapping) through the use of a mobile device (laptop, tablet, smartphone connected to the internet). The need for the integration of mobile devices and a web application emerged from a constraint imposed by the MagixTable (also true for other platforms such as the MS Surface) – that text entry can be done from one pre-existing keyboard at a time. For the kind of activity we sought, this constraint would be significant. To resolve this problem, we developed four virtual keyboards on the tabletop (one for each user). However, users experienced difficulties typing extended ideas on the virtual keyboard during stage 1; the keyboard interaction suffered from input latency and mistyping issues. Thus, the use of mobile devices for input via a web application was considered as a practical solution to this problem for stage 1. This problem demonstrates both the still existing technical limitations of tabletops but also the importance of user input in developing applications for such technologies.

Stage 2. Next, the ideas are presented one-by-one, as digital post-it notes in the middle of the tabletop surface and become subject to discussion amongst the collaborators. For each idea, collaborators make an effort to categorize it in a thematic unit. Functionalities include:

- Each post-it note must be categorized before the next one appears. If controversy exists, an idea can be placed in the "Decide Later" depository to be revisited upon the categorization of other ideas. Post-it notes are automatically oriented to face their contributor, which encourages them to elaborate on the idea. This functionality was implemented as a result of users' feedback and is consistent with previous work by Wigdor and Balakrishnan (2005) showing that orientation can play an important role in collaborative interactions around tabletops by signifying ownership and directing attention.
- Thematic units can be created by any participant using the virtual keyboard. Once a participant begins the categorization of an idea (e.g. either begins to type

a thematic unit or simply touches the post-it note), others must wait as only one keyboard is presented at any given time. Thematic units can be renamed if needed.

- Participants can drag and drop a post-it note over a thematic unit to categorize it. Post-it notes can be manipulated in order to move them across the surface, rotate and resize them.
- In this stage participants cannot edit ideas, or generate new ideas/notes, and thematic units cannot be deleted. These design decisions aimed to scaffold the collaborative activity by allowing time for learners to consider all contributed ideas before making significant decisions.

Stage 3. In this last stage, more flexibility is given to the participants to finalize their taxonomy. In addition to the above, users can now edit ideas or generate new ones, delete ideas or thematic units that are less promising, and reallocate ideas into thematic units for a better fit. Overall, students engage in a collaborative decision making process, leading to the construction of a group artifact – a taxonomy of their ideas.

Studies with Ideas Mapping

To examine the affordances of surface computing for collaborative decision making two studies were conducted with groups of university students: a small pilot study and an experimental investigation.

The pilot study

Participants and setting

Four university students, aged between 22 and 27 years old, were recruited to participate in a short activity around the tabletop. The scenario involved the "creation of an action plan that can improve university students' experiences at the Cyprus University of Technology, including social and educational aspects". The session was video recorded and analyzed.

Video analysis and preliminary findings

An exploratory approach was used in video analysis to assess the observed user experience. General goals guided the analysis such as: to categorize the kinds of interactions that take place around Ideas Mapping and to look for evidence regarding the affordances of multi-touch interactive tabletops to support collaborative decision making. One of the researchers considered the video corpus in its entirety – a total of 57 minutes. Most interaction occurred during the second and third stages of Ideas Mapping, which became the focus of the analysis.

The researcher repeatedly watched the video, marked segments of interest and created transcripts in an effort to categorize the types of discourse and gestures used by the group members around the tabletop. A preliminary coding scheme emerged from the analysis including eight categories of verbal and non-verbal behavior (Table I). This coding scheme will be further refined as more studies are conducted in this context. Furthermore, the video analysis showed that students collaborated intensively in constructing their taxonomies. For 57 minutes, students worked together and their interactions were rich in cognitive elements (e.g. information sharing, elaborating, questions and answers), almost always accompanied by physical

Spoken contributions	Gesture contributions
1. Information sharing – defining/describing/ identifying the problem 2. Proposing – proposing a thematic unit/new idea 3. Elaborating – building on previous statements, clarifying 4. Negotiating meaning – evaluation of proposal, questioning/answering, expressing agreement/ disagreement, providing arguments for/against 5. Stating consensus – summarizing ideas, metacognitive reflections 6. Other talk – tool-related talk, social talk, laughter	7. Communicative gestures – show on the table without touching, dominating/ blocking gestures 8. Touch gestures – resize, rotate, type, move something across, random touching or touching to explore

Table I.
Preliminary coding scheme – interactions around Ideas Mapping

communicative and touch gestures. Furthermore, participants seemed to have enjoyed their involvement in the session, as evident in their social talk and laughter (Table I). In this sense, the pilot study provided initial evidence that Ideas Mapping and multi-touch tabletops can stimulate discussion and physical interaction around shared artifacts; thus, the technology can provide a mechanism for the support of collaborative decision making. This is consistent with previous research findings discussing the affordances of interactive tabletops to support collaboration (Buisine *et al.*, 2012; Harris *et al.*, 2009; Morris *et al.*, 2006).

Experimental investigation

Participants

To further examine the value of multi-touch interactive tables for collaborative decision making, we recruited 17 postgraduate students in Cyprus, aged between 22 and 45 years old ($M = 30$), to discuss a more "sensitive" topic – World Peace. The participants were divided into five groups: three groups of three students and two groups of four students, suitable for the four-sided tabletop. All, but one student, had no prior experience with using a multi-touch tabletop.

Procedures

In this study there was a preparatory phase before students engaged in group work around the tabletop. That is, stage 1 of Ideas Mapping was completed in distance, during the week before the tabletop investigation. The preparatory week aimed to allow students to research the scenario and think at their own pace. During the preparation week, students were tasked to investigate the topic, think creatively and record at least ten ideas into the Ideas Mapping web application.

The following scenario was presented to the students:

> Your team works at a non-governmental organization dealing with global peace. Your project is to create taxonomy of your views and ideas regarding how we can promote global peace using technology.

The specific scenario was chosen to be a rather sensitive one and personally relevant to the students since Cyprus is a country in a long lasting political conflict. The next phase involved co-located collaboration around the tabletop. Following the preparation week, each group met face-to-face and engaged in collaborative work as described in stages 2 and 3 of Ideas Mapping. Briefly, the ideas of each group were presented on the tabletop one-by-one. Students engaged in discussion and physical interaction with the tabletop in an effort to categorize the ideas in thematic units (i.e. taxonomy of ideas).

Data collection

A questionnaire was administered to all the participants at the completion of the activity. The questionnaire aimed to assess the perceived user experience concerning Ideas Mapping and the learning task overall. Moreover, the sessions of all five groups were video recorded for subsequent video analysis.

Analysis of questionnaire data

The questionnaire included 30 Likert-type items with a seven-point agreement response scale (from 1 – completely disagree to 7 – completely agree). These items measured three constructs of interest:

(1) Collaboration support, assessing the extent to which students thought the technology supported their collaboration such as, "The technology helped me work effectively in my group", "The technology met my needs as a collaborator".

(2) Learning experience, assessing the extent to which students were satisfied with their learning experience overall, such as "Overall, my collaborative learning experience was positive", "I am satisfied with my experience through this activity".

(3) Usability satisfaction (adapted from Lewis (1995)), assessing the extent to which students were satisfied with the usability of the system such as, "It was simple to use this system", "I can effectively complete my work using this system", "I like using the interface of this system".

All participants (a total of 17 students) completed the questionnaire. First, the internal consistency for each subscale was assessed using Cronbach's α; all three subscales had acceptable internal consistency (Cronbach's $\alpha > 0.80$). Then, subscale mean scores were calculated for every participant (i.e. an un-weighted composite score for each participant on each subscale) followed by computation of descriptive statistics. As shown in Table II, means were well above the midpoint of the seven-point response scale for all three measures, suggesting that the technology was positively endorsed by the participants overall. Specifically, the participants thought the technology supported their collaboration ($M = 5.53$, $SD = 0.22$), and were satisfied with their learning experience ($M = 5.77$, $SD = 0.51$). With regards to usability, participants found the system usable overall ($M = 4.93$, $SD = 0.77$), but individual item means pointed to some aspects which may need improvement. The rating average was lower

Table II.
Subscales statistics and descriptive statistics

Subscale	No. of items	Cronbach's α	M (SD)
1. Collaboration support	6	0.94	5.53 (0.22)
2. Learning experience	5	0.96	5.77 (0.51)
3. Usability satisfaction	19	0.97	4.93 (0.77)

Note: $n = 17$

for three particular items in this scale, suggesting that we should improve the way participants recover from mistakes ("The system gives error messages that clearly tell me how to fix problems" $M = 3.00$; "Whenever I make a mistake using the system, I recover easily and quickly" $M = 3.36$), as well as extend the application to include more functionality ("This system has all the functions and capabilities I expect it to have" $M = 3.88$).

The questionnaire also included an open-ended question concerning the pros and cons of using tabletops for collaborative learning activities. Using open coding (Strauss and Corbin, 1990), we found a few ideas (codes) in students' responses. In particular, several students commented on how the tabletop promoted collaboration, helped them maintain attention to the task and was enjoyable to use. For example, one of the participants commented: "The tabletop helped us collaborate and the resulting product was a group effort. It helps you pay attention. I also found it very enjoyable". Moreover, students often pointed out the capabilities of the system that enabled effective collaboration, such as:

> It was nice all of us could use the tools at the same time, to rotate a note, to make it larger to read, or to put it in the box to revisit later.

On the negative side, a few participants found the virtual keyboard difficult to use and that the system needed improvement in handling mistakes; these issues were consistent with the findings from the quantitative measures of the questionnaire and contributed to further refinement of Ideas Mapping for future investigations.

Overall, the results from the questionnaire data analysis showed that users' experience was positive: students thought the technology supported their collaboration, were satisfied with their learning experience and found the system usable. These results provided further evidence of the affordances of multi-touch tabletops to support collaboration on decision making activities.

Video analysis

Detailed video analysis was contacted to the video data (approximately 50 minutes of video for each group). Similar to the pilot study, through video analysis, we aimed to categorize the kinds of interactions that took place around Ideas Mapping. Furthermore, in this study we sought to document the themes and ideas relevant to peace demonstrated by the collaborators and to look for evidence regarding the affordances of multi-touch interactive tabletops to support collaborative decision making on sensitive topics.

Due to the scope and space limitations of this paper the detailed video analysis and results are presented elsewhere (Ioannou *et al.*, 2013). Briefly, Ioannou *et al.* (2013) found that, despite the sensitivity of the scenarios in the study, the cognitive interactions observed during the activity were typical to small group collaboration around problem-based activities. In fact, the preliminary coding scheme of Table I was found to fit the new dataset well, with minor refinements. Moreover, students produced interesting taxonomies of peace ideas reflecting the result of their consensus decision making. These taxonomies highlighted a number of areas where research could focus in terms of using technology for peace making (Ioannou *et al.*, 2013).

Discussion – conclusion

Ideas Mapping builds on the principle of affinity diagramming to allow participants to analyze a problem and brainstorm around possible solutions while they construct a taxonomy of their ideas. In this work, following the individual generation of ideas, the multi-touch application supported a two-stage collaborative activity that promoted ideas sharing, negotiating, sorting and constructing a group artifact while coming to a consensus. The study reported on the functionality of Ideas Mapping and the user experience while interacting with it. We also reported initial findings regarding the affordances of surface computing for collaborative decision making. Below, we summarize our findings in terms of implications for future research and practice in the area.

Suggestions to practitioners

- Designers should focus on engaging students and instructors in the design process of educational surfaces computing applications. The user-centred cycles of design employed for the design of Ideas Mapping helped us identify interaction challenges and obstacles. The active engagement of students and instructors made it possible to design an application that fits their needs and goals.
- Current interactive tabletop technologies come with a lot of user interface limitations, such as the constraint of only one input at a time and the problems with inputting text using virtual keyboards, which resulted in using external tablets as input devices. These limitations should be taken into account when designing applications for multi-touch surfaces.
- Findings from self-reported measures and observation (video) data suggest that students positively endorsed the use of multi-touch interactive tabletops for small group work. They enjoyed their involvement in the sessions while the technology allowed for dialogue and collaboration.

Suggestions to researchers

- This work provided evidence that Ideas Mapping and multi-touch tabletops can stimulate discussion and physical interaction around shared artifacts; students collaborated intensively in constructing their taxonomies and their interactions were rich in cognitive and physical contributions. Thus, the technology can provide a mechanism for the support of collaborative decision making and should be further explored in this context.
- Understanding collaborative decision making around tabletops is currently limited. It is thus important to establish a coding scheme of the interactions evident around this technology (particularly, the synergetic dialog and physical gestures) to be able to examine the phenomenon further. The preliminary coding scheme of this study should be expanded, refined and reused in similar settings.
- Ideas Mapping aimed to make the affinity diagramming technique more collaborative. By allowing for an extension sorting activity, it provides a way for participants to negotiate around an emerging group artifact and make sense of challenging problems. This argument however warrants further investigation with experimental studies comparing Ideas Mapping to typical affinity diagramming sessions.
- Traditional user experience evaluation methods (e.g. questionnaires) were useful in evaluating Ideas Mapping. However, we found that qualitative evaluation

(e.g. video analysis and the establishment of a coding scheme) was also important in revealing interesting patterns of interactions amongst the participants and the technology beyond what was self-reported. Researchers should consider employing qualitative evaluation methods in future studies in similar settings.

- Our investigation did not involve any comparative study relating interactive tabletop interactions to interactions around traditional table and post-it notes. We considered this to be beyond the scope of our present work but we do think it will be worth investigating in the future. Such comparisons will enable designers to further develop the application to match the users' mental models regarding affinity diagramming.

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