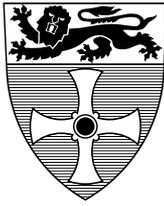UNIVERSITY OF
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How do people collaborate using paper documents around a table. An observational study.

A. N. Sulaiman, P. Olivier.

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The task was to individually annotate a particular document, combine individual annotations into one common document, and finally to jointly write a summary for the document. The study was analyzed within a distributed cognition framework and examined the task, the participants, and the tools. The analysis demonstrated that many factors contributed to making collaboration work. These include: elements of participants' actions (conversations, body position, gaze, gestures, and stylized actions), spatial characteristics of the setting and participant behaviour (dividing the workspace, and the position and orientation of artefacts on the workspace), and the artefacts themselves. These observations have been used to identify the factors that should be taken into account when designing a computer system to support co-located synchronous collaboration.

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Suggested keywords

How do people collaborate using paper documents around a table

An observational study

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taken into account when designing a computer system to support co-located synchronous collaboration.

Key words: annotations, collaboration, digital tabletops, distributed cognition, observational studies, tabletop collaboration.

1.   Introduction

Dillenbourg (1999) characterized three criteria for regarding work as collaborative: interactivity, synchronicity, and negotiability. Interactivity here is not measured by the frequency of interaction, but to the degree it supports useful collaboration. Synchronicity refers to actually doing things together as opposed to cooperation, which is normally asynchronous activity. Finally, negotiability which is made possible by the symmetry requirement, as opposed to imposing points of views between asymmetric partners. This sense of negotiability does not only refer to negotiations related to the task itself, but also to the negotiation of coordination between participants. In learning sciences there is an emphasis on the "co-construction of knowledge" as a result of the collaborative process (Liponen 2003). Liponen quoted Rochelle and Teasly's (1995) definition of collaboration as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem."

These definitions, leave open a number of parameters including the number of people involved (i.e. starting from two), whether the participants are co-located or not, and the time span of the activity (i.e. could be as short as minutes, or span a number of years). The term collaboration can therefore be used in a very broad sense. This study is concerned with collaboration around a table, an activity that is usually of short-duration

(minutes to a few hours) and which takes place among small groups (two to six). This type of collaboration can also be described as co-located, face-to-face, synchronous collaboration.

Collaborating around a table is an everyday activity. Moreover, it is difficult to imagine people collaborating together around a table to perform any task, without paper playing a major role throughout the process. People accumulate experience over the years in using paper to aid them in carrying out different tasks both individually and collaboratively. Believing that paper plays such an important role, the study was designed with an emphasis on paper use in paper-related tasks as part of a collaborative activity at a table.

Digital tabletops allow us to consider interface design from a new perspective. Instead of attempting to design computer software that makes the computer screen more like a desktop; the opportunity exists to digitally enhance beneficial aspects afforded by tabletops. This requires components that are significantly different from those used in traditional desktop interfaces. A number of questions must be answered regarding different aspects of the design and their role in supporting collaboration, including: the spatial arrangement of the user interface elements; communication and coordination among the people involved; access to the different tools and resources used; and input mechanisms. The main goal of this study is to gain an understanding of traditional collaboration around a table, with the goal of informing the design to digital tabletop systems for educational settings. As Tang (1991) noted "We need to observe how people collaborate then build software that facilitates collaboration based on those observations, giving the users the 'tools' that are 'naturally' defined in face-to-face interaction".

2.   Related work

The digital tabletop is a relatively new research field, thus most existing hardware and software systems are experimental prototypes. One of the first digital tabletop systems was Wellner's 'DigitalDesk' (Wellner, 1993).   The three most important characteristics of this system were: the projection of digital images on the surface of the desk and onto paper documents, the response of the system to user input with pens and bare fingers, and the system's ability to read paper documents placed on the desk through the use of cameras. DigitalDesk was designed for a single user but Wellner also proposed a technique for allowing two remote users to share their desks as part of a remote collaboration. Following Wellner's pioneering work, a number of researchers developed tabletop interfaces, where each targeted a particular application or explored specific interaction ideas. Dietz and Leigh (2001) developed the DiamondTouch technology which is a multi-user touch technology suitable for developing tabletop interfaces. Shen et al's (2003) UbiTable, which is based on the DiamondTouch table, supported inter-device communication between mobile devices and the tabletop and included the concept of dividing the table space into private, personal and public spaces. Streitz et al. (1999) introduced the InteracTable as part of their i-Land interactive landscape project. The InteracTable was designed to allow for the creation, display, discussion and annotation of information in a simplified manner. Scott et al. (2004) proposed a number of guidelines for designing co-located collaborative tabletop displays based on a number of observational studies and experimental prototypes centred on the notion of territoriality.

Although observational studies have been conducted to explore collaboration around traditional tables, or the use of paper, no study to date addresses paper use in a

collaborative setting around a table. Tang (1991), observed a small group of people in a collaborative design task using a shared drawing space. In this study large pads of paper where used as a drawing space. Scott et al. (2004) studied collaboration around a tabletop in two settings, a casual setting for three types of activities: Puzzle table, Pictionary® table, and Lego® table; and a laboratory setting which involved small groups (2-3 participants each) performing a layout planning activity to create a furniture layout plan using furniture-like paper cut-outs. Pianesi et al. (2005) studied group interaction around a horizontal whiteboard. In fact, the majority of tabletop observational studies are evaluation studies of the digital tabletop prototypes, rather than inquiries as to the nature of paper-based tabletop collaboration itself.

Paper usage has been examined in a number of studies, but only as used by individuals. Wellner's DigitalDesk (1993) supported interaction with paper documents for single users. Ashdown and Robinson (2004) implemented a 'personal projected display' that provided a large horizontal interactive surface supporting paper based interactions for an individual user, or to allow two remote users to collaborate. O'Hara and Sellen (1997) conducted a study of the difference between reading paper and electronic documents, and outlined many of the advantages of paper over electronic documents (more on this in section 4.5.3). Sellen and Harper (1997) examined how studying paper usage in knowledge-based, document-intensive, organizations can provide useful information for modifying or making new system designs. They suggested that studying paper usage can inspire new designs in three ways: (1) by showing how the current digital alternatives are inadequate because papers are often used as 'work around' for poor designs; (2) how the current hardware and software need rethinking to match the

'functionality' of paper in work processes; and (3) how paper will continue to be the ideal choice for certain document-related activities.

3. The study

3.1. The procedure

Our study was conducted on two groups. The time allocated for the study was one hour. Each group was asked to follow the following procedure (Refer to appendix A for a copy of the instructions given to the participants):

Stage 1: Participants were asked to read and annotate a five-page document individually (20 minutes).

Stage 2: As a group, participants where asked to combine their notes onto a new clean copy of the document producing a new version which all think of as an enhanced copy of the original document. (20 minutes).

Stage 3: As a group, participants were asked to use the annotations from the new version of the document to write a summary in the range of 20-30 lines (10 minutes).

Participants were motivated by telling them that they were to make a 5-minute presentation based on their summary, though no presentation was actually made.

3.2. Participants

Two groups participated in this study. The first group was of three male participants who all knew each other well, and were all post-graduate students in the School of Computing Science. The second group had four participants, three males and one female. Again the group members knew each other well. Three of the participants were postgraduate students doing research with the School of Computing Science at Newcastle University, and one participant was a research assistant also in the School of Computing Science.

3.3.   The setting

The procedure was carried out around a round table with four chairs. Three video cameras were used to record video of the whole process from three different angles.

3.4.   Materials used

All participants were provided with a copy of the document to work on, a highlighter pen, a writing pen, and a set of 'Post-it' notes. The group was also provided with some blank pages for the final summary.

4.   The Observations

To analyze this study in a distributed cognition framework, it is necessary to take note not only of the task the group is trying to accomplish, but also the activities around the task to organize collaboration, and the tools used in carrying out the task (Perry 2003). The collaborative tasks in this study were at stages two and three, that is, annotating the public document, and writing the summary. Studying the activities around a task means that we had to observe all the actions (and absence of actions) carried out by the participants including speech, gestures, body position, and their handling of the tools involved in the task. The tools involved in this study were the table, a number of pens and highlighters, and papers (documents and summary pages). Each of these elements and their interactions with each other has to be observed.

The analysis is divided into sections. The task itself is described first, including the transitional representations that lead to the final outcome (Perry 2003). Details on how space was used are then discussed; these include the territories and paper position with respect to these territories, and orientation issues (Scott 2003; Toney and Thomas 2006; Kruger et al. 2003; and Tang 1991). A number of additional factors are also

considered including: conversation analysis (Morris and Winograd 2004; and Carbtree 2003), body position, how documents are handled in public space, gaze (Knapp 2002, and Shearer et al. 2006); and gestures (Shearer et al. 2006; and Kendon 1997). Finally, we consider tool use, with emphasis on the affordance provided by each and the tool's main purpose (Norman 1993). The use of paper as a tool is discussed in more detail due to its central role in the whole process (O'Hara and Sellen 1997).

4.1.   The task

As mentioned, the final stage in the study was to produce a summary of a document. Participants were explicitly asked to first annotate their local copies, then a common public copy, before creating the summary. The tasks in this study include reading and annotating paper documents individually, annotating a public document collaboratively, then writing a summary page jointly (co-authoring). Annotation was emphasized due to its important role (Marshal 1997) in personal study and small group learning activities.

Emphasizing collaborative authoring was one of the main design goals, but the fact that in each group only two participants played active roles in this process, and collaboration basically took the form of one dictating to the other what to write, made the observation of the co-authoring activity problematic. A future study with a modified procedure that puts more emphasis on the writing process plus more careful selection of participants is being planned. In the course of discussions after the study the participants confirmed the naturalistic nature of the task.

4.2.   Transitional representations

A key focus of a distributed cognition analysis of work is the nature of representations and how they are used to help people carry out their work (Hollan et al. 2000). The transitional representations in this study were the annotated documents that each participant had created at the end of stage one, the shared annotated document produced in stage two, and the summary produced during stage three. Moreover, Hutchins and Palen (1997) considered communicative behaviour in co-located synchronous collaborative activities, as in this study, as "the representations by which a socially distributed cognitive system does its work"

Annotated documents were the outcome of stages one and two. What to annotate and how to annotate were the main issues of discussion during stage two which was the stage in the study that involved the most collaboration. Annotations were either notes in the margins, or highlighted sections, and in two cases 'Post-it' notes. Moreover, some participants relied on notes alone, others used highlighting exclusively, and those who mixed the two either used them in parallel, or highlighted important sections first and, in a second pass, summarized the highlighted sections in the form of notes on the margins.

From a public perspective, annotations can be considered as "third party value-added information" to any document (Röscheisen et al. 1994). Hollan et al. (2000) regarded such representations as a way to help people see what is more relevant at a certain stage to decide what to do in the next stage. This was particularly true of the summary writing stage in which participants relied almost solely on the annotations to the public document. The summary created, was a new representation of the original document and was the final outcome of the whole process.

4.3.   Spatial elements

The functions of space in collaborative work has been classified into three main categories: spatial arrangements that simplify choice, spatial arrangements that simplify perception, and spatial dynamics that simplify internal computation Krish (1995). This has been extended to consider the combined effect of space, gesture, and speech (Hutchins & Palen, 1997).

4.3.1   Territories

Scott (2003), Toney and Thomas (2006), and Tang (1991) all observed that when a group collaborates around a table, the table is implicitly divided into three territories: personal, public (group), and storage. For this study, a round table was used, and four chairs were distributed around it (Figure 1). The way in which participants used the table space was consistent with past observations as can be seen in figure 1. Participants used the spaces directly in front of them as their personal spaces, the space to the left of their personal spaces as storage spaces, and the space in the middle of the table for collaborative tasks. This was observed through all the stages of the study.

**Figure 1: The table was divided into local, storage and
public spaces. (stage three: writing the summary)**

4.3.2. Papers' positions with respect to territories

The position of papers on the table was related to how the table was divided. When a participant was working on his/her local copy and not collaborating, papers were placed in the personal space, near the edges of the table. But when collaborating, even the local copies of the documents were pushed slightly toward the centre (the public space). This can be seen in the contrast in the position of papers in figure 4 (where there was no collaboration) with those in figure 5 (during a collaborative task).

On the other hand, the public document was mostly placed in the public space when there was a group discussion about the document, but when a participant needed to work on the public document, it was pulled toward that participant, but in a position that is almost between the public and the personal space. In figure 2, it can be seen that at the beginning of the collaboration stage (making the first annotation on the public document at the beginning of stage two), the participant was still hesitant to pull the document closer to his space (figure 2-a), so he worked on it in the public space. After a short period, when no other participant showed clear interest in participating directly in writing (from which he probably concluded that he will be the one in control of the document) he pulled the document closer to his space and changed its orientation to better suit him (figure 2-b).

<div align="center">(a)   (b)</div>

Figure 2: Public document position. Fig.(a) is at the very beginning of stage two, and Fig.(b) is after a short period of time at the same stage.

4.3.3. Orientation

Orientation played a very important role in the collaboration. The public document was reoriented on a number of occasions, in particular between the participants that were most actively engaged in discussing what and where to annotate. In each group, two participants took up such roles. Papers in the public area were either rotated towards one of these two or placed at an orientation that was accessible to both of them. In some instances, where only a short gaze was required, the document was not reoriented, and participants just moved or turned their heads to ease reading without reorienting. However, in general, orientation served more than one purpose where there were cases corresponding to all the functions of orientation as suggested by Kruger et al. (2003). These were to simplify comprehension, for coordination (like in indicating ownership of the document by reorienting it towards oneself), or for initiating communication with others by reorienting the document towards them. See Figure 3 below.

(a)   (b)

Figure 3: Orientation. Fig.(a) shows orientation of the public document in public space (stage 3: writing the summary). Fig.(b) shows orientation of a local copy to initiate communication (stage 2: annotating the public document).

4.4.   The people

To be able to understand how people collaborate, it is necessary to observe not only the actions that are directly related to accomplishing a task, but also hidden actions or even the absence of actions that might indirectly have contributed in accomplishing the task (Hollan et al. 2000).

4.4.1. Conversation

Conversation was one of the main methods of collaboration. It was noted that most of the conversation was conducted between two participants in each group. These two participants were in fact the active ones who undertook most of the work. Following Morris and Winograd (2004) it is possible to categorize the type of conversations as follows:

Talk related to carrying out the actual task: which in this case was either annotating or summarizing. This was the main type of conversation and was taking place

almost the whole duration of the collaborative task; participants relied on the ability to have this type of conversation for carrying out their collaborative task

Strategy planning: At the beginning of each stage, participants spent some time discussing how to proceed through that stage. For stage two, they discussed who was going to do the actual annotation. And for stage three, they discussed who was going to do the writing and who was going to dictate. Once again, this indicates a reliance on conversation for 'strategy planning'.

Coordinating access to 'shared' resources: In this study, and as explained above, two participants actively participated in the processes of annotating the public document and writing the summary. Other participants played passive roles and only acted when explicitly asked to do so. Therefore, coordinating access to the shared resources was mostly limited to two participants only. The 'shared' resources referred to here were the public document and the blank summary page. Morris et al. (2004) pointed out that the need for coordination (and hence the possibility of conflicts) may increase as the number of participants and the number of resources increase and as the size of the table gets smaller. So for only two participants, only one or two shared resources, and a reasonably large surface to work on, no conflicts nor explicit coordination effort were expected or observed. Access was simply coordinated through 'social protocols' or 'standards of polite behaviour' (Morris et al. 2004).

4.4.2. Body position:

By observing the postures of the participants throughout the experiment, four basic postures where noted:

4.4.2.1. Sitting almost straight leaning slightly on the table – working individually

This posture was used during stage one of the study where no collaboration was required. Participants leant slightly on the table, indicating that they were working by their own (Figure 4.)

| (a) | (b) |

Figure 4: Working individually with papers positioned near table edges (stage 1: annotating the local copies)

4.4.2.2. Leaning forward toward the centre of the table – collaborating.

During collaboration, all notably leant toward the centre of the table indicating collaboration or the intention to collaborate in the process (Figure 5.)

(a) **(b)**

Figure 5: Collaborating. Leaning forward with papers including personal ones, pushed slightly toward the centre (stage 2: annotating the public document)

4.4.2.3. Leaning backward – no task at hand

This posture was used in two situations: firstly, when a participant finished a task before the others, he leant backward indicating that he completed his task; and secondly, when a participant was idle and not participating in any activity, either because he/she did not want to or because the task did not require his/her participation (Figure 6.)

Figure 6: Leaning backward. Idle-state (stage one: finished annotating the local copy).

4.4.2.4. Hands over local copies

Only one participant used this posture. He leant forward but with his hands completely covering his local copies with no tool at hand. This was at stage two and the task at that time required references to the local copies. By covering them in this way, the participant showed no intension of making such reference, indicating that he might have not been interested in participating. Figure 7 shows this posture. Note that there was another participant with a rather similar posture but the difference was that in this latter case the participant held a pen and thus created the impression that he was still involved (this participant was also participating in the discussion at that point in time.)

Figure 7: Showing no interest in participating at that moment (stage 2: annotating the public document)

4.4.3. Working on documents in the public space

Participants handled, and interacted with, the public document in distinctive ways when it was placed in the public space. From figure 8-a below, one can note the unusual manner in which the pen was held while drawing a rectangle around a paragraph. The participant held the pen perpendicularly to the paper and pulled his hand away from it. This shows his intention to give a better view of the paper, and what is being marked, to

the other participants (an attempt by the participant to increase others' awareness). This participant did not use the pen in this manner at any other time. Also from figure 8-b one can note that the participant (when adding the first annotation to the public document at the beginning of stage two) adopted an uncomfortable position when writing, again to increase the awareness of others of what and where he was writing.

| (a) | (b) |

Figure 8: Special handling of the public document (stage 2: annotating the public document)

4.4.4. Gaze

Knapp (2002) identified five functions of gaze of which three are important to this type of collaboration: information gathering (as the main function of gaze); regulating the flow of communication; and monitoring feedback. Non-verbal behaviour to affect both communication regulation (looking at the face of another person to establish an obligation to interact) and the use of turn-taking signals (asking a question then looking at another participants to indicate that an answer is expected) was observed through the collaborative stages of the study, as was feedback monitoring. When a participant suggested something, replies were either auditory or gestural (generally nodding). Since

collaboration was around a tabletop and all participants could see each other, it was not possible to know how others would reply, so the person making the comment usually looked at others immediately after the comment even though an auditory reply was anticipated. Indeed, gazing at another participant after a comment obliged them to give feedback even if this was not intended.

4.4.5. Pointing, and other gestures and manifesting actions

Deictic gestures (i.e. pointing) played a major role in promoting awareness and coordination. Participants pointed to the public copy, to their local copies, and, to a lesser extent, to the local copies of other participants to attract focus to a certain page or a certain position in a page. See figure 3. Manifesting actions or (stylized actions as characterized to by Pinelle et al. 2003) are normal actions that are exaggerated (stylized) to draw attention and send certain messages. Gestures (Kendon 1997) and stylized normal actions were used to either explain an idea or to promote awareness about a change of state like declaring the beginning or ending of a stage.

For example, aligning pages in a notable manner was used to indicate the completion of a task and readiness for the next (Figure 9). Capping and uncapping the highlighter or pen in 'a stylized way' was used to indicate the onset or completion of a task or readiness to participate in a task. Also, tapping on the table with the fingers or the pen was used to indicate an 'I am still involved' state. In Figure 7 it was also noted that a simple gesture like holding the pen, differentiated the state of two participants as to whether the participant was willing to participate in the current activity or not.

Nodding gestures were used to provide feedback, as discussed in the gaze section, and gestures were also used to explain ideas like the case of drawing a pyramid in air to

explain a graph (iconic gesture). See figure 9-b below. Gestures were also used in coordinating turn-taking (Tang 1991), where in one case a participant threw the public document to another participant across the table informing him that it was his turn to do the next task (Figure 12). Other gestures, like beat gestures were used during verbal descriptions even though in some cases no body was looking at the person talking and making the gesture.

The use of such spontaneous gestures even when they were not made with the intention to be seen by others, supports the assumption that the setting of this study (and consequently collaboration around tabletops in general) allowed participants to act freely and naturally and did not impose restrictions on their 'spontaneous' behaviours.

(a)   (b)

Figure 9: The use of stylized actions to indicate a state transition and gestures to explain ideas (stage 2: annotating the public document)

4.5.   The tools

Tools or 'artefacts' (Norman 1993) play an important role in any collaborative process. They serve as a cognitive tool, and a tool to help coordination. Distributed

cognition theory puts a lot of focus on tools (Hollan et al. 2000) and equates it with humans as agents in the cognitive process. Another theory that puts focus on tools (but to a less extent) in analyzing collaborative processes is the Activity Theory (Kuutti 1995). This theory considers tools as mediators between the subject (the human) and the object (the desired outcome). The tools, in this study were the table, the pens and highlighter, and the papers (the document and the summary page).

4.5.1. The table

The table was basically the environment for the whole study. It afforded a physical support for the persons involved and for the other tools. Its relatively large size allowed for dividing its surface into territories as explained previously and allowed participants to freely move and spread their pages in different spatial arrangements. Quoting from Morris (2006):

> *"Nearly every work environment features desks and tables, and with good reason: tables are well suited to many kinds of information work. Tables' horizontal surfaces afford the placement of objects, and their large surface area affords the spreading, piling, and organization of these items. Chairs afford sitting and relaxing, making work around tables leisurely and comfortable. Perhaps most importantly, tables afford face-to-face collaboration amongst a small group of co-located individuals."*

4.5.2. Pens and highlighters

In addition to the traditional use of writing and highlighting, pens played a role in indicating the participants' state or state transition. As discussed, an exaggerated action of uncapping and capping the highlighter might indicate the start or end of an action;

holding the pen might indicate continuous involvement in a process, and handing the pen or highlighter to another participant indicates a request for action from that participant. Pens and highlighters were also used as pointing devices.

4.5.3. Papers (the documents and the summary page)

Another benefit of the experiment was in observing how people used paper while reading, annotating, and writing, individually and collaboratively around a table. The use of paper is a little more complicated than the other tools above and hence will be discussed more thoroughly. In spite of all the technological advances in display devices and in software dealing with electronics documents, working with traditional paper is still preferred by the majority of people (O'Hara and Sellen 1997.)

O'Hara and Sellen (1997), compared reading paper and on-line documents and stated three major advantages of paper documents.

- **Ease of annotation while reading**

- **Freedom of movement within and between documents**

- **Spatial layout due to their occasional usage on large flat surfaces.**

Annotations while reading was used in this study as it was a requirement, but it would have been interesting to note whether the group would have used annotations as an intermediate stage to create the summary if not have been asked explicitly to do so. Regardless, participants annotated in three ways: highlighting, writing on margins, and in two cases using post-it notes.

Movement within and between documents was noted very frequently. This, as O'Hara and Sellen (1997) stated, served three purposes: Planning (getting sense of the overall structure of the document), for reference (checking for facts like definitions,

figures, and so on), and for checking understanding (re-reading to confirm or clarify understanding). All these cases where noted during the study. Figure 10 shows three participants going through their documents searching for a term definition.

Figure 10: Movement within a document
(stage 2)

As for spatial layout, O'Hara and Sellen (1997) listed three reasons for arranging pages in different spatial layouts:

- To gain sense of overall structure. This can be noted from figure 11 where one participant laid out almost all the document pages beside each other to gain an overall look of the document.

- To cross reference: The person in charge of annotating the public document used to keep synchronizing his local copy with the public copy to be able to cross-reference between the two.

- To interleave reading and writing. This was used less frequently as in the stage of writing and in most of the time on person was dictating and the other writing.

**Figure 11: Spreading pages to get an
overall look of the document (Stage 1)**

Papers as physical objects also played an important part in coordination, like pushing a paper or orienting it toward someone served as a request for action from that person. In one case, one participant threw the document to another person asking him to take action (Figure 12). The affordance that papers provide in terms of how easy it is to move them, spread them, and navigate through them is a major advantage of papers as compared to any electronic document alternative. Another usage offered by papers is its inherit support for promoting awareness. Others can easily note actions taken on paper and hence being fully aware of the owner's actions and intentions.

It is worth noting also that the presence of a large number of papers on the table also lead to confusion in some cases. In one case, a participant was confused about which papers belonged to his local copy and which ones to the public copy. In other words, the full freedom of laying out pages on the table without any rules is not always an advantage.

Figure 12: Throwing the public document to another participant (beginning of stage 3 – strategy planning)

5.   Discussion

For people to collaborate effectively, they need to communicate explicitly with each other; coordinate their actions, turn-taking, and their access to the shared resources; and to maintain full awareness of the collaborative environment. It was interesting to discover that even a simple collaborative task as the one observed in this study, was enough to demonstrate most of the findings of other researchers in the field of collaboration around tables (traditional or electronic), like conversation, territoriality, orientation, the use of gestures, and other minor details about how people collaborate. It is also noted that no studies that we know of analyzed the use of gaze, body position, and tools in a similar collaborative setting.

The behaviour of the two groups was basically similar. Although one group was of four participants and the other was of three participants, in both cases there were two active ones that did most of the work while others participated only when asked to. The ways in which the coordination was done and the tasks themselves were carried out, were almost identical and were in correspondence with similar observations by other

researchers (Tang 1991; Morris and Winograd 2003; Pinelle et al. 2003; Kruger et al. 2003; Scott 2003; Toney and Thomas 2006; and others). This implies that these are basically the traditional, implicitly agreed-upon, ways of collaborating in similar settings, and that it will be quite acceptable to draw general conclusions from the behaviour of these two groups.

5.1.   Where tabletops fit in

If we keep tabletop interfaces out of the discussion and try to imagine a technological solution that can help participants perform a similar scenario in a better way, this would definitely be a rather difficult task. Traditional settings of co-located networked computers, or interactive whiteboards, or combinations of both, are the most obvious solutions, but each of these will sacrifice many of the main practices that help in making collaboration work. These settings do not support face-to-face collaboration forcing participants to completely change their conversation type, strategies, and style; how awareness is maintained; and how to coordinate access to resources or turn taking.

Natural collaboration relied greatly on free-style conversation in this study. Conversation played a vital role in all aspects of the process (discussing the actual task, strategy planning, and turn taking). Also working in a face-to-face setting with no visual boundaries between participants, allowed them to use gestures, gaze, and postures in explaining ideas, adding meaning to their discussions, and in turn taking.

Some of the weaknesses or delays that were observed during carrying out the task given to the participants were: the need to re-write annotations in stage two where a copy and paste feature would have been a great help, the need to hand-write the summary,

difficulty in searching for a specific term in the documents, and in one case getting confused by the large number of papers placed on the table.

Tabletop interfaces have the ability to combine the benefits of traditional tables and computer technology. A good tabletop interface design will maintain the advantages of a traditional table and traditional collaboration environment and overcome the weaknesses caused at the same time by this traditional medium by the use of computer technology like for example to ease data entry, exchanging data between participants, speed of data finding and retrieval, cost saving by reducing the amount of printed media, and so on.

An important point that needs thorough study is the important positive role that paper played in the collaborative process and the fact that people still prefer to use paper over computers in many document-related tasks like reading and annotating (O'Hara and Sallen 1997). Nevertheless, among other commercially available technological alternatives like computer screens and interactive whiteboards, tabletops, with a large horizontal interactive surface, still have the potential to provide the best alternative, or even pertain the use of traditional paper and mix it with technology like in augmented tabletop interfaces (like the LivePaper system proposed by Robinson and Robertson 2001).

A common and important problem that typically occur in collaborative sessions, is the free-rider problem (persons that do not participate actively in the collaboration process). This problem was present with the two groups in the study conducted. Investigating what digital tabletops can afford to reduce this problem is another challenging research area (Morris 2006).

5.2.   Conclusions and lessons learned for future designs.

For small, co-located, groups collaborating around tables, it can be concluded that collaboration is mainly accomplished by four factors: (1) Conversation as the main method of communication for carrying out the task itself, for strategy planning, maintaining awareness, and coordination. This emphasizes the importance of allowing unrestricted **voice communication** between participants. (2) Postures, gaze, gestures, and pointing were used very frequently to acquire feedback, promote awareness of ones current state, indicate a state transition, and to aid coordination. This point emphasizes the importance of unrestricted **visual communication** between participants. (3) Workspace and the distribution of artefacts on the workspace was also an important factor in collaboration. The workspace was implicitly divided into personal, storage, and public (group) spaces. The position of artefacts and their orientation in the workspace reflected ownership and intentions of participants, and helped in coordination and in promoting awareness. (4) The tools involved (the table, pens and highlighters, and paper) also played an important role in coordination and maintaining awareness in addition to their traditional uses. All the tools served multiple purposes beyond their original intended use. The consequences of replacing any tool with a digital alternative must be carefully studied as the digital tool may replace the tool's original intended use, but may deprive users from the other side-uses that may be as important.

Hutchins and Palen (1997) in their distributed cognition analysis of collaboration in a cockpit in a commercial airliner reached a similar conclusion where they stated that "space, gesture, and speech are all combined in the construction of a complex multi-layered representations in which no single layer is complete or coherent by itself." The

setting is different and the aspects analyzed are slightly different than this study, but the general idea that the ability to have unrestricted voice and visual communication in addition to freedom of using the space are vital elements in effective collaboration.

This study, though does not give detailed design guidelines, but hopefully helps in better understanding the factors that play part in natural collaboration and in highlighting the different factors that designers of future collaborative systems should not ignore.

Appendix A: Instructions given to participants.

Summary of the study

The study involves a group of four participants. Each of you must read and **annotate** a five-page document. This must be done first **individually**. Then, as a group you will be given a new clean version of the same document and should sit together and combine your notes onto the new version that you all agree to be better than the original. The next stage is to use the new document to write a short summary together based on the annotations only and then to use this summary to make a quick presentation.

The whole procedure is paper based.

Annotations may include:
Writing on margins, between lines and in empty spaces.
Writing on post-it notes
Highlighting text, Underlining, and circling
Sketching and drawing
Using symbols like *, +, X,…

Procedure
The study involves 4 stages and should last no more than 60 minutes.

Stage 1: **20 minutes**
Each of you will be handed a copy of a document (the same document for all). You should read it carefully and annotate it (annotations can be any or all of the ones listed above). The annotations will be used to create a summary at a later stage and then this summary is used to make a presentation, so annotations are important because there will not be enough time to return to the original text.

Stage 2: **20 minutes**
Next, you should all sit together and you will be handed a clean copy of the same document. The task is to combine only the annotations that you all agree to be useful onto the new document. This will produce a document that all agree to be a better version than the original. The idea is that such a fully annotated document will be easier to read and review in the future.

Stage 3: **Maximum 10 Minutes**
As a group, you should together create a short summary ranging from 20-30 lines only, based entirely on the annotations from the newly created document.

Stage 4: **5 minutes**
One of the group members must make a short presentation based on the summary.

Thank you for your participation.

Appendix B: Sample Scripts

Following are two scripts of short durations (about two minutes each) taken from the two groups at different points in the collaborative process. These specific periods of the collaborative process were specifically selected as they show many of the points discussed previously and help in providing some context to the hole discussion.

Group 1: At the very beginning of stage two.

The public document is placed on the middle of the table facing P2.

P1 rotates the public document in an angle between him and P2 and writes 'Group 1' on
  top.

P2 nods in agreement while looking at P1.

P3 looks on his local copy all this time.

P1 nods also.

P2: Ok, should we go through each section and look at the important things?

P1: (looking at P2) Yes we should.

P2: OK.

P3 looks at them, then looks back at his local copy.

P1: (looking towards P2 and P3) Did anyone write anything about the abstract? (and pulls
  the public document slightly and rotates it towards him, but still his local copy is
  directly in front of him, and above it towards the middle of the table, the public copy.)

P2 moves his local copy from his storage space to his personal space in front of him.

P2 then reads what he wrote about the abstract then looks at P1's local copy.

P1 reads what he has written.

P3 looks at p1 while he is reading.

P3 checks P1 again after he has finish reading, then reads what he has written about the

abstract and points with pen on the section he is reading.

P2 glances at P3's document and nods in agreement.

P1 looks at the others and say: So what should we abstract?

P2 suggests what to write.

P3 looks at P2 at this time.

P1 starts writing on the public document in an awkward posture while it is still almost in

the middle and rotated slightly towards him.

……

P1 Should we do it on a paragraph by paragraph basis? not that you can easily tell what

the paragraphs are!

P2 starts describing how he went about annotating the document.

P1 and P2 take a quick glance at P3 checking if he has anything to say.

P3 keeps looking at his local copy (which gave a message that he is not going to say

anything.)

P1 then starts reading his next comment.

Group 2 : During stage two.

While discussing annotating the public document and still at the abstract of the

document. P3 is the one annotating the public document. This script is for a duration of

two and a half minutes.

P1: Em..(looking round at other participants, then turning to P2) what have you got there

on the abstract about the cause?

P2: Em (pointing with the pen at the paragraph under discussion, and playing with his hair using the other hand, and looking back at P1) about the presumption?

P1: Yeh.

P2 reads silently to himself.

P3 reads part of the paragraph under discussion loudly, to confirm the part under discussion.

P2: Yeh.

P1: Yeh.

P3: Yeh.

P2: Yeh.

P2 Reads the part that he has highlighted.

P1: (looks at the pages in front of P3 and P2) that's probably the most important part. Isn't it?

P3: yeh. I have highlighted a bit before that (and points on it with his finger) which is (reads the highlighted bit.)

P1 points with his finger to the same area on his page. and looks at P3's page to re-checks the position.

P3 reads from the paragraph, explain some points and uses his left hand in a form of an explanation gesture, then looks at P1 seeking agreement.

P1 looks at P3 and comments on the abstract in general.

Discussion between P1 and P3 with a lot of finger pointing to parts of the abstract on the local copies.

P2 and P4 kept silent looking at their local copies and looking up every once in a while.

P1 (looking at P4), What do you think P4?

P4 laughs and fixes her posture without saying anything.

P1 and P3 starts a discussion again.

P3 Marks part of the public document based on the discussion.

P4: What I don't get is what is meta-cognition.

P1: It's about you thinking about thinking.

P3: (at the same time) It's thinking about thinking.

P4 looks at each of them while talking, then nods in understanding.

P1: You are right, it doesn't define it well (and starts going through the pages of his local copy searching for the definition.)

P3: It doesn't define it well.

Then the four participants starts talking together and P1,P3, and P4 start looking into their documents searching for the definition.

P3 finds the definition and starts reading it using a hand gesture that indicates 'explanation state'.

P4 finds the definition and highlights it on his local copy.

P1 finds the definition and finger points at it on his local copy.

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