Chapter 5

DO FEWER LAPTOPS MAKE A BETTER TEAM?

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Abstract: This study explores the effect of laptops on team of students working collaboratively around a table. Complementary quantitative and qualitative analysis have been performed with 8 groups of four participants who had to carry out a travel planning task with 2, 3 or 4 laptops. The analysis of subjects' gaze locations for each dialogue utterance shows that laptop owners look at their display in 65% of the coded events. This ratio is quite independent of the number of laptops in the group. Consequently, the higher the number of participants with a laptop, the less attention is available for dealing with coordination. The coding of dialogue transcripts allows a qualitative analysis of the dynamic of roles and of group coordination. If group experience and individual differences remain determinant, having more laptops fosters parallel individual search. But, at the same time, laptops hamper the emergence of a clear strategy, reduce leadership and tight coordination and seem to result in poorer performance. These findings seem to indicate that collaborative learning could be more effective with an asymmetrical layout, i.e. with fewer laptops than team members. This might scaffold the emergence of roles and foster social interaction: team members with no personal displays tend to regulate the activities of other or at least pay more attention to group interaction. Due to our qualitative methodology, we present these are provisional results.

Key words: Tabletop, laptop, CSCW, CSCL, dialogue analysis, gaze location.

1. INTRODUCTION

As collaboration was shown to be more fluid when occurring face-to-face than when occurring via computers, many tabletop systems have been developed during recent years. However, these tabletops either have been developed for very specific tasks (e.g. Shen et al., 2002, Underkoffler &

Ishii, 1999; Buxton, Fitzmaurice, Balakrishnan & Kurtenbach, 2000) or embedded in sophisticated and proprietary components (e.g. Shen, Everitt & Ryall, 2003; Prante, Streitz & Tandler, 2004). No affordable, generic and reliable system has been developed so far. Therefore, very few studies of real tabletop supported collaboration have been carried out outside the field of games (Ryall et al. 2006) or of systems tested only with students in a university (Sundholm, Artman & Ramberg, 2004).

Our team is conducting research on mid-tech interactive tables designed for enhancing student collaboration and learning. By 'mid-tech' we mean that these pieces of furniture embed interactive devices (LEDs, microphones …) but do not look as computers (with key board, large displays, …). Prototypes have been developed and are reported in another chapter of this book (Kaplan et al, this volume). The idea of embedding computational power in a table could however appear as silly since students often bring their own laptop to carry out group assignments. The influence of laptops on teamwork is however ambivalent. On the one hand, allowing people to use their laptop brings more resources to the group (laptop as private space and tabletop as public space), but, on the other hand, the fact people somewhat disappear behind their display may hinder social interaction. The challenge of tabletop design is precisely to benefit from the computational augmentation while avoiding the drawbacks. Surprisingly, our community has poor knowledge on the role of laptops on co-present teams compared to the vast literature on computer-mediated collaboration. We can for instance find studies on gaze analysis instance in videoconferencing (Vertegaal, 1999) but not in co-present collaboration with laptops.

This study therefore uses data from an experiment initially designed for evaluating an interactive table but in which we became increasingly aware of the importance of the laptops in collaborative processes. After the presentation of the theoretical perspective (part 1), measures of users' gaze location are compared for different conditions (part 2). A qualitative analysis is then provided to shed some light on the influence of laptops and team strategy (part 3) before the final discussion (part 4).

2. RELATED WORK

This section presents existing studies relevant to our topic: working collaboratively, around a table and with some technological augmentation.

2.1 Tabletop systems

The tabletop approach relies on the postulate that collaboration is more fluid when people are around a flat surface than when it occurs via computer mediation (Bly, 1988; Tang; 1991). Not only do face-to-face conditions allow a higher degree of workspace awareness (Tang, 1991) and therefore more fluid coordination, but computers themselves may hinder collaboration. Desktops and laptops have been built for a one-user/one-computer design paradigm (Steward, Bederson & Druin, 1999). Only one user has access to the input devices. For visual output, multiple users have to sit very close to each other to be within the range of perception of the screen. The audio outputs can more easily reach multiple users but they have so far not been exploited for that purpose.

Many tabletop systems have been developed to integrate computing facilities within a horizontal surface. Most prototypes are based on computer display, which is top projected on a traditional table from a beamer fixed on the ceiling or rear-projected from below the table (Patten, Ishii, Hines & Pangarno, 2001; Scott, et al., 2002; Shen et al., 2002). More elaborated systems embed flat display in the table. The user interaction with the display is achieved by cameras in top projection or the use of touch screens. Prante et al. (2004) presents a system connecting large tactile display components with smaller individual components, where fine grain conflict detection allows true synchronous object edition. DiamondTouch is a large tactile display that detect two hand gestures and which user is gesturing (Diez et Leigh; 2001). DiamonSpin is a Java tool kit that manages the interactions between multiple users and the tabletop, including reorientation mechanisms (Shen, Vernier, Forlines & Ringel, 2004).

Several systems combine a shared tabletop with connected laptops, which then create personal and public spaces, raising issues such as ownership and right of access. The Augmented Surface system (Rekimoto, 1999) allows connecting personal laptops to public displays. Content can be 'hyperdragged' from one space to another by direct manipulation, for instance by sending the laptop pointing device “across” the limit of the laptop screen. The Ubitable (Shen et all 2003) offers a transitional personal space that is displayed both at the bottom of the laptop screen and on the corner of the table. Documents in this transitional space are visible to the other persons around the table but can be accessed by them only when their owner moves it to the public space.

Despite 10 years of great prototypes and even commercial products, tabletop environments are yet far from being widespread. The main reasons are probably that they are based on proprietary software and/or expensive hardware. Another explanation could be that the key problems that have been addressed by these artifacts, such as moving documents across private and public spaces or changing the orientation of the shared displays, are less critical for collaboration than some basic issues. What is the effect of having a personal display such as a laptop while interacting with co-located teammates? Relatively few studies have done observations on the effect of introducing personal devices within a collaborative task performed around a table.

Gubman, Oehlberg & Yen (2004) compared the performance of a group of three persons in two conditions: around a unique laptop or around the MapNews table, which is specifically designed to geographically browse information about countries of the world. The results of the evaluation questionnaire showed a preference for their table (in the context of this specific task). More interestingly, they have also made observations about collective laptop usage. It appeared that a laptop provides a narrow social focus since users had to gather closely to get the same view. Pointing was easier (due to proximity) but less precise (due to the laptop's small screen) than on the table. Moreover only one person had control of the laptop even if backseat users could use gestures or vocal commands.

Sundholm et al. (2004) presented qualitative observations of groups using an interactive environment, which was composed not only of wide horizontal and vertical collective surfaces but also of connected personal displays. This study focused on how ideas were constructed and negotiated in relation to the artifacts and the layout of the room. These authors showed that many different kinds of transitions between personal and public spaces were spontaneously used (showing personal material to the others, getting shared content to work on it, etc.). Moreover they noticed that the different roles on the display (e.g. showing VS listening) were taken by different persons over time, even if personal preferences were observable (e.g., some person were staying in their personal display).

Tabletop design guidelines (Scott et. al., 2003) offer hints about possible positive (+) and negative (-) effects of personal displays:

- *Interpersonal Interaction (-)*: As separate and personal displays are not visible by everyone, laptops can hamper communicative gestures, such as pointing.
- *Transition between activities (+/-):* (-) The operations required to move content from a personal to a public display can slow down the collaboration. (+) The computer interactivity allows users to move content quickly between software applications either on their personal display or the public one (if projected)
- *Transition between tabletop collaboration and external work (+):* As a mobile device, the laptop provides a link between places and activities. A

user can access the content of his emails, personal files or bookmark at anytime and almost anywhere.
- *Simultaneous user actions (+):* multiple laptops allow simultaneous work on objects through shared editors and parallel work on duplicated or complementary contents.

The reviewed work illustrates the fact that personal displays have positive and negative effects on collaboration. To better understand these effects, we need to zoom in the collaborative process.

2.2 Collaborative processes

In the field of collaborative learning, scholars have tried to predict team outcomes by manipulating variables such as group composition (group size, group heterogeneity, gender…) or task features (convergent/divergent, procedural/declarative…). Decades of studies revealed that too many factors interact in too complex ways; collaboration cannot be treated as a black box. Instead, scholars have to zoom in the collaborative process to understand how collaborative settings influence social interactions and how these interactions produce cognitive effects (Dillenbourg, Baker, Blaye & O’Malley, 1996). Several types of interactions have been studied such as the quality of explanations (Webb, 1991), mutual regulation (Blaye, 1988), argumentation (Baker, 1999), conflict resolution (Doise, Mugny & Perret-Clermont, 1975). These various types of interactions have in common that they lead students to verbalize knowledge that would otherwise remain tacit. In the same perspective, identifying what would be the effects of introducing laptops around a tabletop requires looking at the social interactions that they support, hinder or modify.

A middle grained description of the processes occurring during ideas construction within a group is proposed by Sundholm et al. (2004). Their model of how ideas are collectively constructed and negotiated, which is inspired by Shneidermann (2000), consists of a loop of four phases that correspond to different group configurations: (1) Discussion; (2) Work by themselves; (3) Interruption of individual works by a participant; (4) The participant presents his individual work to the others.

Scott et al. (2004) have studied how the organization of territories was emerging during group activity and was supporting group interactions. In the case of tabletop, they defined these territories as a mix of spatial and computational properties that are delimited with little or no verbal negotiation and that support coordination mechanisms. They identified three kinds of territories:

- Group territories are spaces used to perform collective activity or to assist other. As these spaces have to be accessed by everyone, they have their place in the center of a tabletop. Ambiguity of responsibility was observed when different participants had an equivalent actual access to a group territory.
- Storage territories are areas dedicated to unused material, such as personal belongings or items not currently useful.
- Individual territories are safe places when one wants to disengage from the group activity. Theirs frontiers are flexible according to people, the available space and can take advantage of visible barriers. A laptop would offer a perfect individual space, until it is ostensibly shown to others.

Gaze patterns have been studied as indicators of group dynamic. Argyle & cook (1976) estimated that about 60% of conversation in **dyadic groups** involves gaze and about 30% involves mutual gaze. The different frequency of gaze between listening (75%) and speaking time (41%) was explained by Kendon (1967) by the fact that the speaker is looking more intensely at the beginning of his utterance (to check attention) and at the end (preparing to give the floor). Fewer gazes were observed in face-to-face conditions when the topic was difficult, as it required more concentration (Vergtegaal, 1999). In remote teamwork with a interface, participants established eye contact (mutual gaze) through the video channel when they were engaged in activities such as joking or discussing about strategy (Joiner et al. 2002), which both require more social feedback. Besides regulation of the flow of conversation, three other functions of gaze patterns can also be identified (Joiner et al. 2002):

- Monitoring how others react to my communications and actions,
- Communicating emotion and relationship,
- Avoiding distraction by restricting visual inputs.

In larger groups (more than 2 persons), gaze patterns are of course more complex and various. The ambiguity of who is addressed has to be considered. The 75/41 ratio between listening and speaking time that we mentioned for pair discussion becomes 47/70 for multiparty discussions, denoting that the speaker has to show whom he is addressing (Vertegaal & Ding, 2002). Moreover, gaze has a function of regulating the arousal within the group, where individuals manage their level of intimacy or public appearance (Vertegaal & Ding, 2002): people who look more at others are more looked at in return.

Actually, gaze is only one way for regulating conversations. In videoconferencing, since mutual gaze is usually not available, it is replaced by explicit addressing (Isaacs & Tang, 1993), i.e. mentioning the name of the addressee or other conventions (e.g. using "…" in a chat to indicate that the sentence will be continued in the next entry). Gaze patterns change dramatically when people are not only talking to each other but also acting together: for instance, gaze frequency drops from 77% to 6% of conversation time when subjects interact about a map (Argyle & Graham, 1977).

Another field of research that is relevant for the laptop/tabletop debate is the study of shared representations in teamwork. A basic principle for shared editors is "what you see is what I see" (WYSIWIS): the different users edit the same document, which is permanently updated by the modifications performed by any team member. This shared representation provides the team with a shared referential space that, in addition to previous communication and group initial common grounds, helps to achieve interpersonal communication (Clark & Wilkes-Gibbs, 1986; Clark, 1996, Fussel et al, 2004). Because this co-constructed representation is more persistent than the dialogues, it often becomes the group working memory, i.e. a representation of the state of the problem to be solved (Dillenbourg & Traum, 2006). However, the WYSWIS principle does not hold when there are multiple users or complex tasks for which it is necessary to distribute sub-problems among team members. In this case, scholars developed so-called WISIWIS-relaxed interfaces that enable different partial views of the document but which nonetheless sustain coordination with 'workspace awareness tools' (Gutwin & Greenberg, 1999). Awareness tools inform team members of what their teammates are doing. The use of laptops in teamwork lies at the heart of this tension between supporting coordination space while enabling individual actions.

3. QUESTIONS

The design of new collaborative technology can be informed by a better understanding of the use of laptops in teamwork. Our target situation is a session in which 3 to 4 students gather around a table in order to collectively do their class project. Our general research question was: *Are laptops beneficial to teamwork around a table?* Since most tasks require at least a laptop, this question does not concern the presence or absence or laptops but the number of laptops in the team. Our hypothesis is that the number of laptops influences roles distribution and patterns of communication, which would be measurable by the analysis of gaze patterns. More specifically, we hypothesized that more laptops would lead to more individual work and fewer collective discussions.

4. METHODS

This contribution reports side-observations of a quasi-experiment carried out by our master students for evaluating an early proto-type of the REFLECT table (see Kaplan et al, this volume). This table captures conversations with microphones and display participation patterns with a matrix of 128 LEDs embedded in the table. In the earlier prototype used in this experiment this matrix of colored points was actually projected by a beamer located on the ceilings. The tables included an adhesive whiteboard in the center on which the matrix was beamed or on which the users could draw anything they wanted to. The experiments were conducted with a variety of tables having different shapes and dimensions. The independent variable was the presence and absence of the beamed matrix on this whiteboard. The experiments revealed that the participants did not pay much attention to this matrix. The first reason for this lack of attention was that the visibility of the matrix was too low under normal lightening conditions. The second and more interesting reason was this central space competes with individual laptops for capturing the users' attention. While the first reason has trivial implications, the second triggered our interest and raised the previously mentioned research question. The experiment was conducted with teams of 3 or 4 students using 2 to 4 laptops. This variety of conditions, which would be detrimental to a proper experimental study, gave us the opportunity to study the role of laptops in a broad range of situations.

4.1 Task

Each group of participants had to elaborate an air journey for two persons, including multiple flights. They had to search flights on Internet websites (a list was given) in order to maximize the length of the whole journey. The journey had to satisfy the following constraints: 1) not to come back to a country previously visited, 2) to stay between 2 and 4 days at each stop (therefore doing only direct flights), 3) to avoid transits between airports of a same city, 4) the total costs of ticket had to below 75,000 Swiss Francs for two persons. The participant had 30 minutes. The last constraint, the budget, was not highly coercitive, as most teams did not manage to spend all money within 30 minutes. This task requires team members to coordinate parallel flight search while keeping track of locations and dates.

4.2 Participants

The participants were EPFL students. No specific constraints (age, gender) were imposed. Instead of paying each participant, we decided that four randomly selected participants would win a travel voucher for CHF 100. Altogether, 24 sessions were run and recorded. These experiments yielded a rich data set that presents an important diversity of collaborative styles and performance. We restrict our analysis with the 13 sessions with four persons talking in English or French.

4.3 Analysis

This contribution includes two forms of analysis. We start with an *extensive analysis* of the 13 experiments focused on four elements: (i) use of the laptops, (ii) use of the whiteboard, (iii) problem solving strategy, (iv) respect of the task rules, (v) mechanisms for coordinating location and dates. This analysis reveals that the number of laptops is a key factor to understand the dynamics of this collaborative task. It was used to select 6 experiments to be analyzed more intensively. This *intensive analysis* was run on 6 experiments, two experiments with a team having 2 laptops, two for 3 laptops and two for 4 laptops. For each condition, we selected one group performing well and the other rather poorly.

As previously mentioned, the conditions of these experiments were not equivalent: the table shape, the laptops positions and even the rigor of the experiments vary. Hence, we do not proceed to a statistical comparison of team performance, but analyze the emergence of group phenomena such as the team strategy or the type of leadership.

4.3.1 Coding and counting

We developed a coding scheme for participants' visual attention. The main location of each participant's gaze was coded for each verbal message. Five frequent gaze locations were identified:

- One's personal laptop
- Paper sheet with instructions or were to write down the results
- Whiteboard on the table
- Other participants' laptop
- Other participant

This coding does not provide a duration measure for gaze locations but counts co-occurrences between verbal messages and gaze location. Only the main gaze location during a verbal message is counted. Short gazes within a longer visual fixation were not written down. This gaze analysis constitutes a medium grained description of visual attention that is relevant to our research questions and appropriate to amount of data to be processed.

We record gaze location even for participants who are involved in a communication episode (e.g. C's gaze is recorded even if A speaks to B).

The dialogues have been segmented into messages based on two criteria: speaker changes and topic changes. This segmentation and coding of gaze location is subjective but we did not proceed to dual coding as we were not aiming at producing statistics. We defined an episode as 'collective discussion' when at least 3 (out of 4) participants were looking at each other during dialogue.

4.3.2 Qualitative analysis

For each group, the transcription of verbal exchanges, enriched with the previously described gaze coding, was annotated in order to identify patterns of interaction among participants. The qualitative analysis was inspired by the Theureau's Course of Action framework[1], even though it was only very loosely applied. Episodes of collaboration were identified, as moments of stable coordination between participants' individual activities. These episodes and the overall group collaborative style were systematically described according to the following criteria:

- Which strategy is used by the group; which roles emergence?
- Which tools are used and how?
- How does information circulate between people and tools?
- What is group performance?

5. QUANTI'TATIVE RESULTS: HOW MUCH LAPTOPS ATTRACT VISUAL GAZE

Figure 1 compares the distribution of gaze toward the different locations. The average number of verbal communication with the gaze directed toward other participants appears to be quite constant, whatever the number of laptop in the group is: from 25%, with 4 laptops, to 31%, with 3 laptops. Obviously, when the number of laptop is lower, the average ratio of gaze toward one's own laptop decreases and the frequency of gaze toward the instruction sheet and whiteboard or toward other's laptop increases.

[1] See http://coursdaction.net to have information and material about Course of Action Framework

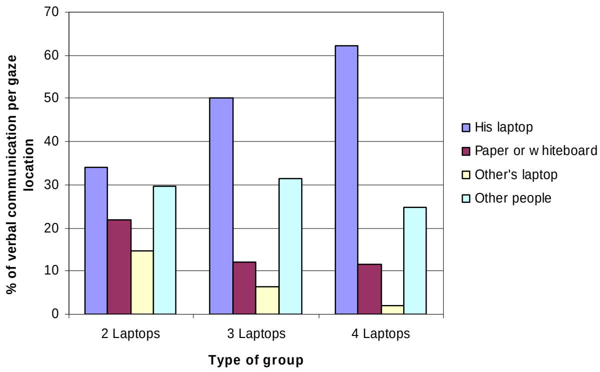


Figure -1. Gaze distribution between groups, according to the number of laptops

The average frequency of gaze toward one's own laptop decreases in figure 1, simply because the number of laptop owners decreases. It is actually constant (figure 2). If one counts the proportion of gazes on one's own laptop only for those having a laptop, this ratio stays between 61 and 69%. Since gaze locations are counted every time a message is emitted, this means that a laptop owner spends approximately 2/3 of verbal exchanges with his gaze on his laptop display. Considering that laptop owners tend keeps their gaze focused on their display during silence, the laptop appears to constitute some kind attention black hole.

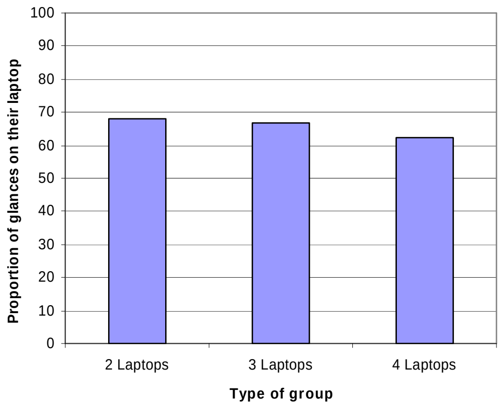


Figure -2. Proportion of gazes of laptop owners on their own laptop

These results suggest that when more laptops are present, less attention is available for coordination. However, these results should be taken with care not only because they come from few participants but especially because the aggregation of the 6 groups in 3 different conditions hides important disparities inter and intra group that we address now. Figure 3 shows the same data for each group. The proportion of gaze toward one's own laptop is important for those who have a laptop: between 45 and 79% (figure 3 a).

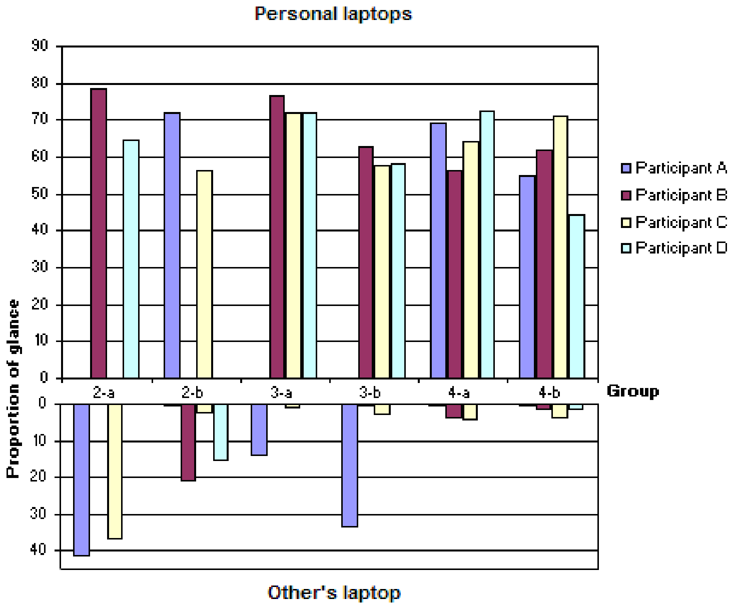


Figure -3. Proportion of gaze toward their personal and other’s laptop for the different participants of the different groups

Looking on another participant’s laptop (figure 4 b) is of course more frequent for participants without laptop: participant A in group 3-a and 3-b, participants A and C in group 2-a, participant B and D in group 2-b. These two results, looking at one's own laptop or somebody else's laptop, confirm the attraction of laptops, stronger for participants with a laptop but also observable for participants without a laptop.

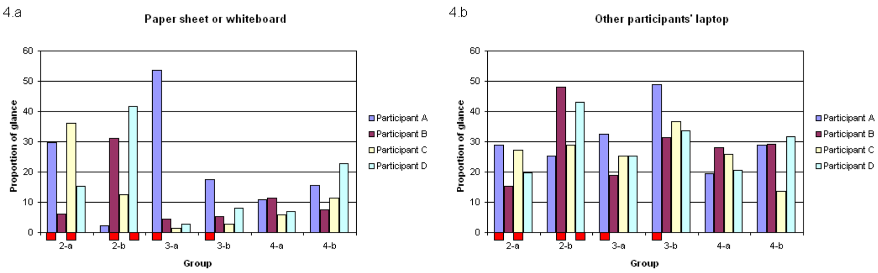


Figure -4. Proportion of gaze toward the instruction sheet or the whiteboard (a, left) and toward the laptop of other participants (b, right). The red squares mark the participants without laptop.

Figure 4a shows that participants have a different number of gazes on the instructions sheet and on the whiteboard. Students without laptops have a higher proportion of gaze toward the instructions sheet or the whiteboard as well as toward others' laptops (fig, 4 b). Gazes to other participants vary from 14 to 48% without main differences between conditions.

In summary, participants with a laptop spent twice as many gazes toward their laptops that toward the other participants. Even the participants without personal laptops direct their gaze to the laptops of others participants. The distribution of gazes is an emerging group phenomenon. The qualitative analysis presented in the next section will shed some light within these processes.

6. QUALITATIVE ANALYSIS

The analysis of the video records and the transcripts reveals that the actual collaboration processes depend on many factors, such as the strategy adopted, the individual knowledge, natural leadership, etc. We first present the analysis of coordination in group 4a and then compare it with what happened in the other groups.

6.1 A case study

Group 4-a was selected because it clearly illustrates the effects of having four laptops (figure 5).

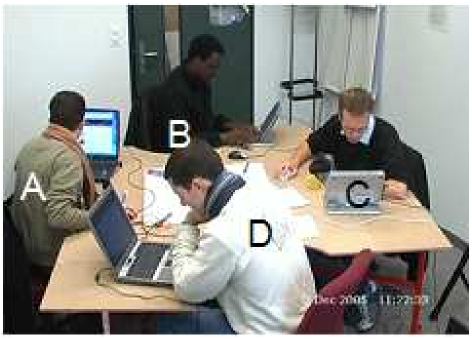


Figure -5. Snapshot of group 4.a video recording

The participants' gaze location is plotted and annotated on figure 5 in order to depict the collaboration phases and events. The upper line shows the moments of collective discussion. The four lower lines represent the gaze location for each participant.

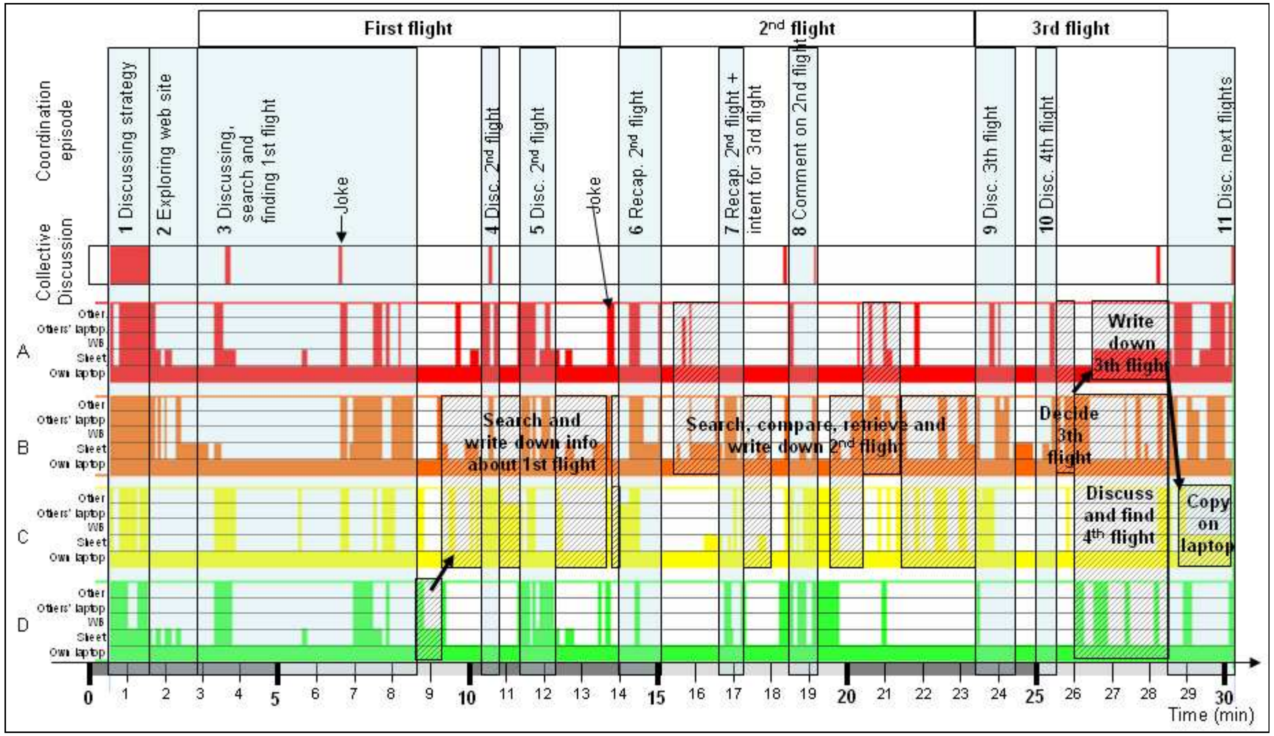


Figure -6. Group discussion and participants' gaze location during the 30 minutes of the experiment. The height of the bars indicates gaze location in a increasing order of sociability: own laptop, instruction sheet, whiteboard, another's laptop and another participant

The shaded boxes in figure 6 show collective coordination episodes, i.e. when individual actions target the same sub-goal. The episodes between these boxes are composed of individual activities or local coordination episodes, which are indicated by smaller boxes with zebra stripes. We now analyze these episodes in detail.

Beginning of the task. In the first coordination episode, the discussion concerns the strategy. Participant C introduces the discussion and proposes a first possible flight. Despite the fact everyone participates to this discussion, all participants look at some point at their own laptops and at the instructions sheet or even put their hands on the keyboard without typing (A and D), showing they are willing and ready to start searching. They nonetheless remain engaged in the discussion. As soon as an agreement is reached about a strategy (starting from a place and finding far but cheap destinations), all team members start searching on their laptop, using one of the web sites suggested on the instructions sheet. The second coordination episode consists of parallel individual searches. No clear strategy is present but coordination emerges from the fact participants make oral comments about the websites they explore. A, B and D mainly look at their laptop and at the instructions sheet. B looks at the others when asking them about their choice but nobody looks at B in return.

First flight. The 3rd coordination episode is initiated by D who asks a question about the flight. The city of departure and arrival are discussed since they have not been discussed so far. Everyone keeps his visual attention on his laptop, but occasional short gazes are directed at others (not counted as they were too short relatively to the gazes on laptops). At the third minute, the choice of the date raises a collective discussion about avoiding expensive periods in the year. Moments of silence during parallel individual search, such as between 4:30 and 5:30, are frequent, sometimes interrupted by short comments about websites or findings. At 6:37, a joke is cracked which moves everyone's attention to the group for a while. At 8:32 B announces that he has found a flight, which is accepted by the others. The following minutes are structured by the necessity of writing down the result and by individual comments regarding to the results sheet. When D hears B's finding, he leaves his laptop, gets the results sheet and starts writing on it. After looking at it for 25 seconds (rectangle on D's line around 9 minutes), D gives the sheet to B (arrow on figure 5), because he does not know what should be written down. At that time, C announces that he has a digital version of the results sheet and that he can also fill in the results there.

Second flight. Finding the second flight takes more than 8 minutes (from 15:20 to 23:40) during which B has a central position. He does not only choose the flight but also compares the information with C's previous findings, writes down the information on the results sheet, transmits it to C and searches for missing information (arrival date, kilometers, etc.). During this time, A and C occasionally help B (searching a cheaper flight for A and writing down B's info on his laptop for C). On the contrary, D states during the 7th coordination episode that he is searching for the next flight, even though no clear arrival airport and date has been established.

Third flight. When B is done writing down the 2nd flight, he asks and receives the date and the airport abbreviation for the flight that is being searched (9th coordination episode). Everyone goes on searching silently for 30 seconds after which C initiates a discussion about the next destination even though the current search is not yet over (10th coordination episode). Right after that, A announces he has found a price and date for the 3rd flight, while keeping his eyes on his laptop. After asking for information about the airport arrival, B gives his agreement but goes immediately back to his laptop, without showing any more interest or writing down the result on the results sheet. As a consequence, A takes this sheet and writes it down. At the same moment (25th-28th minute), while A, C and D discuss the next flight, B, who has been compiling all the information from the beginning, gets confused about locations and dates as he has not taken into account the flight just found by A. The A, C, D subgroup finally agrees on D's very expensive suggestion as they still have plenty of money to spend. The last minutes are devoted to the discussion about the next flights, without finding a precise date and airport combinations and without writing down the 4th flight.

6.2 Identifying roles

The distribution of visual attention during verbal exchanges, show how much participants keep their eyes on their laptop screen: from 56% for B to 72% for D. The instructions sheet also had a significant attraction on gaze: 12% for B and 11% for C (including looking at the list of websites and monitoring B's work). The disparities presented in figures 3 and 4 can be partly explained in terms of the roles played by each participant. General roles have been identified from the confrontation of the six experiments. These roles do not form a proper partition of team: some roles are not played in some teams, one role can be played by two persons or one person may also play partially some role, etc.

Table -1. General roles taken by the participants in the various experiments

Role	Responsibilities
Leader /	Encouraging participants to share goals and information
Strategy	Defining heuristics for searching flights (long flights, hub airports)
	Eliciting the constraints and their application.
	Deciding between alternative flights
	Making proposition/decision about task distribution
Searcher	Finding flights that match the expressed constraints
	Finding additional information (number of km, map)

Role	Responsibilities
Scribe / keeping track	Keeping track of found flights on the whiteboard Reporting results on the results sheet Keeping track of the current search focus

In the detailed analysis presented above, the roles were not cleanly distributed:

- A and D are mainly searchers, even if they participate in the discussion about strategy at the beginning and if A writes down the 3rd flight. Most of their activity is carried out on their laptops.
- C is a searcher but also scribe as he is maintaining a digital copy of the results sheet (with no benefit). All his activities are carried out on his laptop except his participation in the collective discussion.
- B plays all three roles. He participates to the choices of flights, sometimes alone, and triggers most of the collective discussion (leader). He finds two of the three selected flights (searcher) but writes also the results on the sheet (scribe). He stops updating the sheet after the second flight to go back to his laptop.

Because this distribution of roles is not consistent over time and since the team does not elaborate a strategy at the outset, the players fail to respect some task constraints and have a poor coordination. Participant C writes the results on his laptop, making B and D’s writing useless. Participant B plays multiple roles and is hence both the force and the limiting factor of the group’s progress. Sharing the flight search would be more efficient. When B stops writing down the results, he looses track of the different searches and relies on C, who is himself not aware of what is going on since he was copying result from the sheets.

While other factors certainly come into play, the analysis provides evidence that laptops are cognitive attractors (Lahlou 2000)[2], in the sense that they catch participants' visual attention, even when they are engaged in a discussion and that this attraction appears to limit the performance of this group. This attraction is found in many occasions during the experiment and is even more striking during to collective discussions.

- During the initial discussion, the participants are keeping a part of their attention on the laptops and the list of website. After a tacit agreement on a minimalist strategy (starting from an airport and finding the furthest

[2] A cognitive attractor is defined as a set of material and immaterial elements that potentially participate to a given activity and which are simultaneous present from participant’s point of view. It is assumed that, when choosing an activity, a human actor will engage himself in the stronger attractor, within those perceived. Attractor strength is defined according to its pregnancy, the estimated cost and value of the anticipated activity.

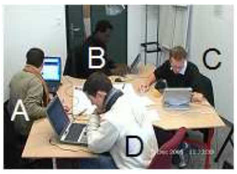
one), the collective discussion about this starting place ends after only one minute, the participants searching on the web.

- The second moment of collective discussion (at 3:40) lasts only a few seconds. Everyone is commenting his search on his laptop. Opposite opinions are exchanged about the pertinence of choosing a period of holydays. Everyone's gazes meet only when B strongly expresses his opinion ("have you ever search a flight price during holydays time?"). After this moment, when the point is made, the discussion continues but with gaze focused on each laptop.
- The third moment of collective discussion is as short as the previous one. The gazes are in contact only during the joke; after that they talk while searching.
- The fourth moment of collective discussion does not last longer and happens at 10:30 when A starts a discussion about the next destination but stops 10 second later when A leaves this discussion to go back to his laptop without more intervention.
- The two short last moments of collective discussion are jokes.

Collective discussion happens when an individual has problems for searching the web or when a joke is cracked or when a point as to be shared (1st and 2nd moments). These moments however remain very short.

6.3 Comparison between experiments

6.3.1 Groups with four laptops

Groups	4-a				4-b			
Performance	**Low**: Three flights with low respect of the constraints				**Low**: Four flights with low respect of the constraints and missing information.			
Participant	A	B	C	D	A	B	C	D
Leader								
Searcher	Flights	Flights	Flights	Flights	Flights	Flights	Flights	Flights
Scribe	Sheet	Sheet	Laptop		WB, sheet			WB, sheet

* Red indicates a strong implication and orange a medium implication in a given role

Table -2. Comparison of groups with four laptops *

Group 4-b shows a different organization than the group we previously analyzed: A and D have the leadership as a subgroup (with more strength for D), while B and C are conducting the search. A collective discussion moment occurs at the beginning (length: 3'28) and, after the website exploration phase, when D writes a list of destinations on the whiteboard. (length: 3'25). Many non-collective discussions happen during the experiment (AD, AB, BC, CD). D uses the whiteboard to write down and to keep track of the found flights (18% of her gazes are on the whiteboard). She therefore spends less time on her laptop (44%, the lowest score for all groups). A writes down found flights, but to a lesser extent (10% on whiteboard only). C also does, but very occasionally.

Their strategy is completely based on the price, which occurs not to be the limiting factor. So they do not select the flights before having evaluated all the destinations. As a result, they not only start coordinating their dates very late (from 16:08, between A and D only) but they also start completing the result sheet even later (at around 25:00).

During the 5 last minutes A and D are writing the list of completed flights on the whiteboard, not acknowledging the proposals and questions of B and C. C ends up doing nothing. Much information about the chosen flights is lost during the transcription on the whiteboard.

6.3.2 Groups with three laptops

Table -3. Comparison of groups with four laptops *

Group	3-a				3-b			
Performance	**High**: 5 flights with high respect of the constraints				**Very low**: No flight written down after 30 min			
Participant	A	B	C	D	A	B	C	D
Leader								
Searcher		Flights	Km	Flights	On B's	Flights	Flights	Flights
Scribe	Sheet WB							

* Participants without laptop are in bold. For any participant, red indicates a strong implication and orange a medium implication in a given role

Group 3-a shows a very clean and efficient separation of tasks. A is coordinating, relaying questions about constraints and eliciting them, arbitrating between possibilities and writing down the flights found by the two searchers. Among all participants in all groups, she has the highest proportion of gazes toward the whiteboard or the results sheet (figure 4.a, respectively 8% and 45%). B and D are exclusively searching for the flights, while C's role is to find the number of kilometers.

A starts writing the expected destinations and dates on the results sheet and completes them with the distance and flight information. However, since several anticipated flights are not possible without stops, she has to erase these lines. After 20 minutes, she starts to write the full itinerary on the whiteboard, which is easier to erase. A's central influence is confirmed by the analysis of coordination questions: On 17 questions about date or location, 10 are asked by the 'searchers' and answered by A, 2 are asked by A when writing down the results, 2 are asked between searchers, while A is writing and the 3 remaining are simple requests for acknowledgment and are not answered. Only 2:21min are spent in collective discussions. A did not initiate all the discussions, but as the results sheet capture less her attention that laptops capture the attention of the other team members, her availability fosters the teamwork. Finding the first flight takes a long time, but the coordination that is built between the searchers allows them to find 5 flights while respecting all constraints.

On the contrary, **group 3-b** shows a strong leadership conflict. The group starts searching flights without defining a strategy. A, who has no laptop, asks B to participate in her search, while C and D are exchanging information in order to find complementary flights. The only collective exchanges are about websites. After 3:45, a discussion starts about the coordination of flights. A conflict appears between A, who prefers selecting many short flights to make sure that they are direct, and D who wants to choose the longest flights between hubs. The discussion lasts until 12:30, even though it is limited to A and D. As nothing is decided, everyone continues searching without coordination. D is spending a lot of time trying to figure out the price of a flight expressed in a foreign currency. At 17:28, C goes to the bathroom and proposes A to use his laptop. They switch places, A becoming C2 and C becoming A2 in our notation. When A2 comes back, there are 3 minutes of silence during which he is looking at B's laptop and then he initiates a new discussion. A list of countries is decided upon, as a compromise between C2 and D. For the remaining time, C2 is mainly searching the flights he has personally proposed. The subgroup ABD is coordinating its searches, A2 looking at both B and D's laptops. After 30 minutes, no flight is written down on the results sheet. This group, unlike others, was given 45 minutes. At the end of their experiment, three flights found by A2BD are written down but none of the flights found by C2 is integrated into the results.

6.3.3 Groups with two laptops

Group 2-a shows another example of efficient specialization. During the 11 first minutes, the subgroups AB and CD, with one laptop per subgroup, are concurrently searching flights to compare websites and destinations. They have moments of discussion to exchange information about their progress. During these episodes, A (without laptop) realizes the difficulty of coordinating direct flights between far destinations. At 11:30, he asks CD to search for kilometers, while he starts assisting B in searching flights.

Splitting the tasks allows one participant to verify constraints. B searches without interruption, while A writes down the successive flights on the whiteboard and coordinates with CD (to tell them which distance has to be calculated). After 23 minutes, C and D finish finding distances for the selected flights. D checks the money spent and searches for the distances whenever a new flight is found. C transcribes the information from the whiteboard to the paper sheet. A shares his time between assisting B's searches, writing results on the whiteboard and commenting on them for C. As B is able to continuously search (reaching the highest ratio for all group: 79% of his gaze to his laptop), the group is able to find seven flights, respecting all constraints. A directs 26% of his gazes on whiteboard, 3% on the sheets, 42% on B's laptop and 29% on other participants.

Table -4. Comparison of groups with two laptops *

Group	2-a				2-b			
Performance	**High**: 7 flights with high constraints				**Low**: 8 flights with very low constraints			
Participant	A	B	C	D	A	B	C	D
Leader								
Searcher	On B's	Flights	On D's	Km	Km		Flights	
Scribe	On WB		On sheet	Check $		On sheet		On WB

* Participants without laptop are in bold. For any participant, red indicates a strong implication and orange a medium implication in a given role

Group 2-b shows an example of clean but loose engagement. B and D have no laptops but they do not participate very much in the discussion nor do they propose destinations. After exploring websites for three minutes, A proposes a solution that allows the selection of 5 flights in one shot and shows his screen to the others. They are trying this solution, discussing the 5 successive destinations; but at 9:40 this solution appears not to work. Later on, after comparing their findings for the first flight, C asks A to find the kilometers. C then searches the successive destinations proposed by the different participants. B is writing down the flights on the sheet and C is writing on the whiteboard both the kilometers and the money spent. The group finds eight flights but with a low respect of constraints.

7. CONCLUSIONS

Even though very few teams were analyzed, this study shows a trend: too many laptops in the team seem to hamper performance. Two main factors may explain this effect.

Firstly, laptops appear to be strong **cognitive attractors**. They captured most of visual attention. The proportion of utterance-related gazes directed at their laptop ranges from 44 to 79%, with an average of 65%. As laptop owners were mostly looking at their screen between verbal exchanges, this means that the proportion of time spent looking at the laptop is actually much higher. Moreover, this proportion appears to be independent of the number of laptops in the team. This implies that the more persons with laptops, the less time was available for thinking about the strategy and the constraints and for sharing information.

In most teams that did not perform well, the students with a laptop did what was the most immediate task - searching flights on websites – even if the found flights were not always useful. In team 4.a everyone started searching without defining any strategy. The result was that no coordination occurred and most of the efforts were useless. In team 4.b, D took the dominant position and arbitrated the strategy and coordinated the flights. Even though she had the lowest proportion of gazes at her laptop (44%), she was not able to see the flaw in her strategy until shortly before the end. Being captivated by their laptops, these participants only communicated with partial and fugitive attention and were likely to leave a collective discussion at the first occasion, even when the discussion was about an important issue.

Secondly, **leadership** occurred to be an important factor in team success. A coordinator or a leader that is able to define a strategic view, to distribute tasks among the team members and to insure constraints management increased the efficiency of the teamwork. In team 3.a, A took a clear leadership position. Being the only member without laptop, her only activity was to keep track of the searches and to coordinate the others. In team 2.a, A took a clear leadership position but he was both coordinating B's searches and coordinating with CD's complementary work. On the contrary, groups without a leader hardly reached good results, even if several members has no laptop. In team 3b, A had no laptop but he was not able to take the leadership and to impose his strategy. In team 4b, B and D had no laptops but they also did not propose any strategies or ideas. They ended up in writing down what A and C had found. It is rather trivial so state that leadership improves teamwork, but the point that may be more important to stress here is the fact that having fewer laptops than group members leads to a diversification of roles that facilitates the emergence of a coordinator role, i.e. some leadership.

Having fewer laptops than team members is not enough to insure team performance. Efficient coordination requires to agree on a strategy and on task distribution and to have an efficient tracking and circulation of information. However, a high number of laptops appears to be a limiting factor. Everyone is tempted to overuse his laptop and has his attention at least partially captured. The remaining attention is not sufficient to manage complex group interactions. Complex issues are not fully addressed by participants who are too busy with their laptops.

The whiteboard also seems to have an influence on the efficiency of the group collaboration. The studied groups have often used it as an external memory. However, in order to be used as a group's shared memory, it seems necessary that at least one participant is available enough (i.e. without laptop) for updating and maintaining its content. Participant A of group 3a used the whiteboard after a while because it was easier to update than the paper sheet. She was then able to keep track of the finished and ongoing searches. She used it to coordinate others participants, verbally referring and gesturing toward the information on the whiteboard. Participant A of group 2a also used the whiteboard, not only to record B's search but also to transmit the information, with a few oral comments, to C and D who where copying, checking and completing the data.

Groups 3b and 2b could use the whiteboard but did not succeed in using it as a coordination tool. Within group 2b, both B and D were transcribing information from the searchers. However, none of them had enough leadership to do more than mere recording and the searchers were too busy to look at the whiteboard. Group 3b used the whiteboard for transcribing the trip that was hardly agreed on during the collective discussion at the middle of the experiment. Due to leadership conflict, only one subgroup used it as a roadmap for their search. The whiteboard was also used by the participants A and D of group 4b but, mainly for individual recording of personal searches. Only at the end, the whiteboard was explicitly referred to by gestures, when the subgroup AD gathered and completed the piece of information recorded so far.

The group 4a is the only one that did almost not use the whiteboard, as everyone was staying busy all the time with his laptop or the paper sheet.

We conclude by the limits of this study. Understanding the benefits and drawbacks of laptops requires a global analysis of the team dynamics, described in terms of roles and coordination mechanisms. Our analysis confirms the relevance a distributed cognition perspective (Hutchins, 1995), in which cognitive functions are distributed over the participants and their laptops but also other artifacts such as the paper sheets and the whiteboard. The drawback of our qualitative analysis is that we can not prove the generalisability of our observations. Especially, our results are bound to a specific task which required a tight coordination and fast circulation of information more than deep conceptual negotiation. The effect of leadership could indeed be lower in task implying creative thinking. Hence, our analysis does not experimentally establish statistically significant effects but reveals phenomena and parameters, which could be used as independent variables in future controlled experiments.

This study nonetheless produces preliminary to design recommendations, Even if the group dynamics can overcome it, our study shows that the design of the table and more precisely the number of individual laptops do have implications on group interactions. The general layout of the table has an effect on collaboration. Regulating access to laptops might avoid hampering rich social interactions. A table dedicated to pedagogical situations could help defining roles: Providing a place without personal display but with tools to monitor the group's activity would for instance foster the leader/coordinator role. For more experienced users, more liberty should be granted to set up the configuration that is the best suited to the collaboration context, including the number of personal displays. Movements between private and public spaces should not be a private functionality but the results of a gesture that act as a public request for taking control of the public space.

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