It's Not How You Stand, it's How You Move: F-formations and Collaboration Dynamics in a Mobile Learning Game

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ABSTRACT

Mobile devices offer great opportunities in the field of collaborative learning. They are especially interesting in their ability to provide digital information while still supporting social interactions between group members, which are essential elements of coordinated and shared activities. However, in truly mobile conditions, e.g. outdoors, the high variability of groups spatial configurations can potentially modify coordination mechanisms. We designed and tested an orienteering mobile learning game to better understand how device use shaped collaboration in highly mobile conditions. The study involved four groups of three students all equipped with tablets. We focused our analysis on the relationship between participants' arrangements (F-formations), their device usage and coordination mechanisms (i.e. awareness, regulation, information sharing, and discussion). Our results emphasize the importance of considering the transitions between arrangements more than F-formations per se. We discuss the implications of these findings for the design and analysis of mobile collaborative activities.

Author Keywords

Collaboration; Coordination; F-formation; Collaboration dynamics; Group regulation; Ubiquitous computing; Mobile learning

ACM Classification Keywords

H.5.3. Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces – Computer-supported cooperative work; K.3.1 Computing Milieux: Computer Uses in Education - Collaborative learning; K.8 Personal Computing: Games.

INTRODUCTION

We now have at our disposal numerous studies discussing how mobile devices can transform learning and/or gaming activities. For instance, how they can enrich the experience of outdoor games [2]. Early work in mobile gaming has led to further experiments in the educational domain, with the hypothesis that mobile multiplayer games could enhance learners' engagement and motivation [19]. Another element in favor of mobile learning games is their potential in enhancing students' social skills [18] by favoring face-to-face collaboration situations and co-located interactions [1].

Social interactions are essential for maintaining coordination in-group activities [9]. The impact of devices' form factor, and affordances on interaction among group members has been studied for tabletops, for instance in respect to awareness and coordination [17], or group size and division of labor [29]. Large screens afford a shared vision of the task and tend to encourage people to interact together [29].

The physical and digital properties of our environment shape the organization and interaction in collaboration [26]. In this article, we are especially interested in understanding the relationship between mobility and coordination mechanisms in mobile and collaborative outdoor activities. Coordination mechanisms are critical in the Computer Supported Cooperative Work (CSCW) and Computer Supported Collaborative Learning (CSCL) literature.

To study how device use and spatial arrangements shape coordination in real conditions, we designed and deployed an orienteering learning game. Our observations focused on four elements: awareness, regulation, information sharing and discussions among group members. We use Kendon's F-formations [20] to analyze people's spatial-orientational arrangements in joint activities, with a focus on how F-formations are created during the collaboration and what are the social interactions happening in these arrangements.

Our study offers insights on how students use tablets to collaborate in an outdoor activity, the F-formations associated to specific coordination phases, and the importance of transitions. We derive implications for design, in respect to regulation, complex information sharing, and control in proxemics interaction in mobile conditions. We further emphasize the need for better tools to represent collaborative dynamics, both from an analytical perspective and a software development/design perspective.

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BACKGROUND

Collaboration mechanism

Our work builds on studies of collaboration from various communities, mostly Computer Supported Cooperative Work (CSCW) and Computer Supported Collaborative Learning (CSCL), but also psycholinguistics. For the purpose of our analysis, we synthesized the previous models and descriptions of collective activities [1, 13, 27, 28] and use a hierarchical model presented in Table 1. Collective activities build upon collaborative or cooperative mechanisms according to the type of activity, which will in turn build upon coordination mechanisms. We clarify the vocabulary used to describe collective activities in the rest of the article, especially: collaboration, cooperation, coordination, awareness, regulation, information sharing and discussion.

<table>
<tr><th colspan="4">Collective activity</th></tr>
<tr><td colspan="2">Collaboration</td><td colspan="2">Cooperation</td></tr>
<tr><th colspan="4">Coordination</th></tr>
<tr><td>Awareness</td><td>Regulation</td><td>Information sharing</td><td>Discussion</td></tr>
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Table 1. Hierarchical levels in collective activity

We consider *collaboration* as *"a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem*" [28]. In collaboration, participants focus on a shared object of work and act together towards the completion of the overall goal. *Cooperation,* on the other hand, "*is accomplished by the division of labor among participants, as an activity where each person is responsible for a portion of the problem solving*" [27]. Participants act towards a shared goal, but each participant performs specific and independent actions to achieve part of the overall goal [1].

We consider c*oordination* as *"the act of managing interdependencies between activities performed to achieve a goal"* [24]. In coordinated work, participants act towards a shared goal dealing with time and organizational constraints. For our study purpose, we selected four mechanisms used in the process of coordination: awareness, regulation, information sharing and discussion.

Awareness involves *"an understanding of the activities of other, which provides a context for* [ones] *own activity"* [10]. It involves knowledge of what others are doing, and how it fits within the larger activity. Awareness covers both high level tasks but also knowledge of physical and spatial arrangements of other participants [14, 15].

Regulation builds upon awareness and relates to people's ability to plan, monitor, evaluate and regulate the joint activity [31, 32]. Depending on the actors involved, Hadwin et al. distinguish several regulation processes: self-regulation, co-regulation and shared social regulation [16].

Information sharing is required to initiate coordination processes. It involves building a common ground [7], with people ensuring a shared understanding, mutual knowledge and assumptions. It also involves sharing information on physical objects such as documents and materials.

In this paper, we only consider *discussion* to reach a decision. It could be defined as a process of talking among people to exchange ideas and reach a consensus based on the information they available. This requires information sharing to begin.

Outdoor mobile gaming

The emergence of connectivity and location services on PDAs and mobile phones, first with WiFi then with iMode in Japan, then Edge and 3G elsewhere led to a number of experiments in pervasive gaming. Early examples include CYSMN [12], Human Pacman [6], Treasure [2], and Feeding Yoshi [3].

The primary motivation for creating such games was to explore new types of engaging experiences in game worlds blending digital and physical elements [23]. Studies of multiplayer games led to insights on design patterns for pervasive gaming and other types of pervasive systems, such as *seamless* design [5]. Within the field of Ubicomp, researchers also leveraged mobile games to evaluate the strengths and weaknesses of their systems from a technical standpoint.

In the learning literature, various research programs explored how mobile games could be used to support learning [18, 19, 21]. Mobile learning as a supplementary teaching technique is a viable way to minimize constraints of time and place in learning environments, but more importantly can support a better contextualization of the knowledge being developed. The engaging aspect of mobile games can help learners get immersed in the learning situation [21]. From a collaborative perspective, mobile games offer better context awareness and more situated learning. Using mobile devices in outdoor learning games can stimulate students to engage in learning, facilitate the organization of conceptual information [18] and promote social interaction and discussion, which will in turn increase their self-efficacy, motivation and confidence [30].

F-formations

Facing formation, or F-formation, is a term and system devised by Kendon [20] to describe a how people adjust their position and orientation to interact together and jointly manage their attention. A typical F-formation arrangement is roughly circular and contains three concentric spatial domains. The innermost space, the o-space, is an internal interactional space where explicit actions are carried out and can be easily captured by participants. The p-space is the area occupied by the participants themselves. The r-space is the surrounding space outside of p-space, which can be considered as a kind of buffer between the group and the outside world. F-formations can take other spatial patterns, including the L-shaped, face-to-face and side-by-side formation (Figure. 3) [27].

The observation that the space in which interaction happens shapes the F-formation and thus the interaction between participants [22] is something we paid special attention to in our analysis. For instance, Marshall et al. [26] observed F-formation and social interactions inside a tourist information center and came to the conclusion that discussions between more than two individuals were actually quite uncommon.

The study of F-formation, can also lead to new interaction techniques. For instance, Marquardt et al. [25] devised new multi-device interaction techniques based on preliminary laboratory studies of F-formation.

DESIGN OF THE ORIENTEERING GAME

With the collaboration of high school teachers from La Martellière (Voiron, France), we co-designed an outdoor orienteering game, which took place in the Chartreuse Mountains (French Prealps), near the high school. The pedagogical objective of the game is to make students aware of sustainable development principles in a pluri-disciplinary approach. The learning game is a multi-player role-playing game, which also aims to develop the users' collaborative skills.

The game requires knowledge from biology, earth science, geography, chemistry, physics and information science. Through the game, students learn how to handle several measuring instruments (e.g. anemometer, luxmeter, thermometer and nitrite test strips), how to understand biotic characteristics of the environment and how to analyze geographical data (maps interpretation). In this context, mobility was important to support skill acquisition as it enables using contextual information and richer interactions among students.

Game play

Students have to discover four areas where to collect biotic data (magenta markers on the map, Figure 1). To access to these locations, students have to solve scientific puzzles related to the areas identified previously (biology, geography, etc.). Several control points (orange markers on the map, Figure 1) are inserted between the four locations. Students are guided to these control points progressively. When they start the race, only the first control point is visible on the map. At each control point, participants have to find a QR code, which reveals the next control point location and gives students the opportunity to unlock clues by answering a puzzle covering one discipline.

To favor rich interactions between groups, the game includes collective activities linked to data gathering skills. To encourage social interactions within groups when using measuring instruments, we introduced three levels of skills: novice, apprentice and expert. These levels are associated to each instrument and represented as badges in the game. At the beginning of the game, each student is considered

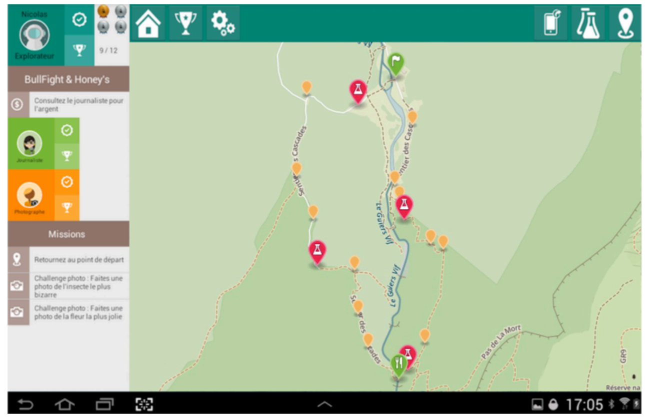

Figure 1. Game map on explorer's tablet (when all the locations are unlocked)

expert on a specific measuring instrument (which they learned before in class). Hence, for each group, there is one expert on anemometer, one expert on luxmeter and one expert on both thermometer and nitrite test strips. During the game, each expert has to share his/her expertise to his/her group so that all the members can acquire knowledge (and badges) on all the measuring instruments and become expert by the end of the game.

We introduced a competition mechanism between groups through a scoring system. The groups earn points when they solve the puzzles. Answering correctly on the first try earns the group the maximum amount of points (500 points), a fewer amount (200 points) on the second try and finally a minimum amount (50 points) on the third or more tries. At the end of the game, the group with the highest total score wins the game. In addition, to maintain participants' engagement during the orienteering game, several "fun" challenges are added such as taking picture of the most beautiful flower and bizarre insects during the race. At the end of the game, back to school, students and teachers vote for the best pictures, and the winning group earns "best picture" rewards.

Collective activities

A group consists of three members. We defined three different roles for each group: the photographer, the explorer (Figure 1) and the reporter. The group should work together to reach a shared goal corresponding to the main mission and "fun" challenges. The main mission consists in finding out all the hidden locations, solving scientific puzzles and collecting data using the measuring instruments. Each role is associated to a specific measuring instrument and players have to perform specific actions that the others can't do. This pushes participants to cooperate and develop coordination mechanisms during the orienteering race. The explorer is the one who is responsible for guiding her/his group. S/he has the map on her/his tablet. S/he is expert on the anemometer. The photographer can scan the QR codes unlocking the next step. S/he is also in charge of taking pictures. S/he is expert on the luxmeter. The reporter has to manage the puzzles and hints on her/his tablet. S/he is in charge of entering the answers and is the one aware of the team score. S/he is expert on both the thermometer and nitrite test strips.

Synchronization flow

Due to the lack of connectivity in the mountain, we didn't integrate data communication across devices, but preferred to develop a simple synchronization mechanism. Participants share verbally unlock codes that they get during the activity (scanning QR codes) in order to synchronize tablets and unlock parts of the game. At the beginning of the game, the reporter receives on his tablet the first puzzle and the explorer guides the group to the first control point to find a QR code (Figure 2, #1). When they find one, the photographer scans it to get an unlock code. S/he needs to pass the code to two others who will type the code into their tablets to update their missions (Figure 2, #2). Entering the code, the explorer gets coordinates of the next control point and the reporter receives a hint for the current puzzle. Once they get all the clues, they answer to the puzzle (Figure 2, #3). Once the reporter enters the right answer, the group earns a number of points, and the reporter also gets a code to update the tablets (Figure 2, #2). This unlock code will reveal the measuring location on the explorer's tablet which can guide them to this point. On the measuring area, students only need to perform the required measurements and collect biotic data (Figure 2, #4). After inputting data into their tablets, they can earn badges associated to their expertise on each measuring instruments responding to several quizzes. Then, their tablets are synchronized again (Figure 2, #2), the explorer getting the location of the next control point and the reporter the new puzzle to solve.

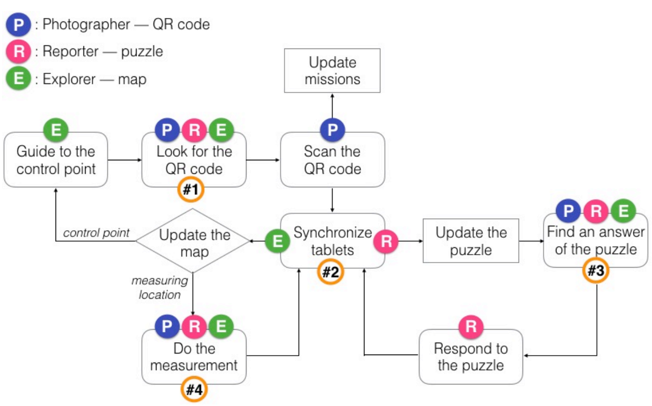

Figure 2. Game flow

STUDY

We conducted the experiment in collaboration with a high school involved in the project.

Participants

We recruited four groups of three students, eight females and four males, aged from 16 to 17. The groups were already set before our experiment, which was part of a larger paper-based learning game. Participants were from the same class. Four teachers also participated to the outdoor activity as tutors and for safety reasons. Students knew each other and were comfortable working together. The teachers also knew the students.

Training

The afternoon before the orienteering session, we arranged a preparation session with all the participants. Students were already familiar with the game world from the larger paper-based game; so we mostly handed out tablets to let them become familiar with the game mechanics on the tablet, discover the different roles we introduced, and let students pick a role of their choice.

During the preparation phase, students conducted an informal mission in an open field on the campus. They learned how to use the measuring instrument related to their role in order to become "expert" in its use. Teachers gave them guidance on how to use these tools and explained them the principles behind the measures. Students were free to ask questions to their teachers. They also practiced inputting biotic data and synchronization codes on their tablets.

Orienteering game

We conducted the study itself following the game structure described in the previous section. Groups started the game ten minutes after the other to limit overlap in the activities. The whole session took about 2 hours and 40 minutes.

Apparatus

We used 12 Android tablets with protection cases, i.e. one per student. All had a resolution of 1280x800 pixels, 10 were 8" Samsung Galaxy Note 8, and two were 10" Acer Iconia Tablets. The two larger tablets were used by explorers.

Recording

During the experiment, one teacher and one person from our research team followed each group to supervise and film the group activity. The students and their legal tutors (i.e. parents) all agreed to the recording. The participants also filled in a survey back at the high school.

Analysis method

One researcher went through the video recordings of the four groups twice. In the first round, she browsed the videos to select segments containing collaborative behaviors. In the second round, she examined these segments in details, marking down when coordination mechanisms took place. This first part of our analysis consisted in analyzing the coordination mechanisms at play in the game. We analyzed students' gazes, gestures and conversations to classify these mechanisms according to the definitions presented in the related work, including regulation, awareness, information sharing, and discussion.

Once we had identified these mechanisms, we focused our analysis on whether some mechanisms led participants to position or orient themselves in specific arrangements; we also looked more precisely into tablet use and micro-mobility. To do so, two researchers scripted in detail the video segments to document the relevant F-formations and the use of tablets (number of tablets used and their orientation according to users) for each identified mechanism. The main researcher also wrote a transcript of the verbal communication on the videotapes, proofread by the second.

OBSERVED F-FORMATIONS

Kendon [20] described three types of F-formation for groups of two persons: L-shaped, face-to-face and side-by-side (see Figure 3, top), and he added a circular F-formation arrangement for groups of more than two persons. Marshall et al. [26] added two more arrangements for groups of four persons: semi-circular and rectangle.

In our study, the groups are composed of three students, we noticed three main types of F-formations arrangements: *semi-circular*, *circular* and *triangular* (see Figure 3, bottom). These arrangements can be influenced by the on-going task, and also by environmental features. Given the mobile nature of the activity, compared to the F-formations described in the HCI literature, the F-formations we observed were highly dynamic. Both within the formation, for example students would keep their formation but move in the same direction, or all rotate at once; and also moving quickly from one formation to another. A transition from one formation to another often indicated a change of the focus in the on-going task.

The *triangular arrangement* happened when two students were standing close to each other on one side with a third student staying on the opposite side at some distance from the others. This arrangement is often caused by an unequal distribution of action. For example, when the photographer got an unlock code; s/he usually preferred to read it out to her/his group members before coming closer to them. S/he was standing alone, in control of the action, while facing the others. The triangular arrangement was rarely maintained for a long time. After giving the code to the others, the photographer would then move forward to form a *circular arrangement*. In the *circular arrangement* students are at a similar distance from each other, it appeared to be the most comfortable position to have a group talk. Most of the discussion we observed had taken place in this arrangement. The *circular arrangement* was the most stable formation we observed, and also the most frequent one. Finally, in the s*emi-circular arrangement*, three students stay corner-to-corner, which let them easily share objects, such as a tablet or an instrument. We also observed this formation, less frequently than the circular one, when a discussion was happening.

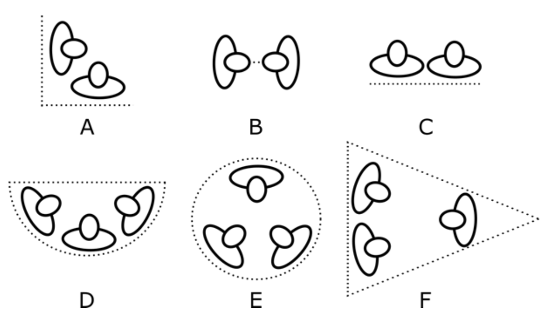

Figure 3. F-formation arrangements. A. L-shaped; B. face-to-face; C. side-by-side; D. semi-circular; E. circular; F. triangular

COORDINATION MECHANISMS

We now describe the various coordination mechanisms and the F-formations associated to them and how students moved to reach them.

Awareness

To identify awareness, we used indicators such as students' gaze, body gesture and conversation analysis. Awareness is subtle and dynamic and often integrated in other aspects of participants' activity. The changes in awareness levels we observed were often due to the use of personal mobile devices and led to transformations in the F-formation. For example, when a student wanted to know what another was doing:

> [In group 2, Anna, the reporter, is inputting the unlock code. Two others, Sophie and David are looking at her (in a circular arrangement). As soon as Anna finished, Sophie and David step close to her to see her tablet for the puzzle (transform to the semi-circular arrangement).]

Awareness levels were also influenced by environmental constraints and mobility derived from the nature of the activity. These constraints may break the F-formation, which, consequently, led to issues related to maintaining awareness. For instance, when participants were walking, they could not see precisely what others were doing, nor the content of the tablets.

> [In group 3, after students got the right answer of a puzzle, they start to move forward. Ben, the reporter, is walking behind while looking at his tablet.]
>
> Ben: Eh guys, I think we get something new.
>
> [Two others, Zoe and Emma didn't hear him and keep walking.]
>
> Ben: Hey, wait, we have a new puzzle on my tablet!
>
> [Zoe and Emma stop and look at him.]

In this example, a group is walking in line. Two students in front are not aware of what Ben is doing, and cannot hear what he is saying. The speaker can only get the attention by speaking much louder.

Regulation

Regulation indicates that students are setting up strategies or goals, or monitoring and evaluating their task. For example, deciding on their next step could be regarded as a strategic action and asking for confirmation of a direction should be regarded as monitoring of regulation. *Regulation* also includes actions that students take to support each other to achieve a shared goal, such as one helping another to read out the data on the instrument.

In Figure 4 (left), the group is doing a measurement. Simon (white shirt) is measuring wind speed. He is holding an anemometer. Susan (the girl on the right side) finds out that Simon is measuring the wind in the wrong direction and points into the right direction. They two form a face-to-face F-formation. The student squatting in front is looking at another measuring instrument. He is in the r-space of the F-formation as he is not involved in the joint activity of the two others.

In Figure 4 (right), Susan, the photographer of the group, is trying to scan a QR code that is hung on a pillar. Simon is helping her by holding the QR code to make sure she can scan it at the right angle. They are forming a L-shaped formation.

Figure 4. Two examples of regulation. Left: Susan is pointing into the right direction for Simon to measure wind speed. Right: Simon is helping Susan to scan the QR code.

We observed regulation behaviors in the form of mutual support, such as reading out data from a measuring instrument to another, or one helping another to check the answer to a puzzle. These regulation behaviors mostly happened within dyads. L-shaped or side-by-side arrangements were mostly used when participants needed to refer to devices, focusing in such cases on the same device or measuring instrument. Face-to-face f-formations were used when regulation mechanism did not require devices.

Information sharing

We observed two main forms of information sharing. The first one is verbal/in-air information sharing, which means passing information verbally without physically sharing devices; the other one is on-device information sharing, which means showing or passing devices to others.

Verbal information sharing always happens when photographers pass codes to others, reporters read out puzzles, explorers give directions or when students share measurement data. For short information, such as the unlock code to synchronize tablets or a measurement to input, students always shared information verbally by reading it out. For example, the photographer always reads out the unlock code as soon as s/he gets it even s/he is far away from others (e.g. Figure 5, left). The explorer gives direction sometimes when the group is walking. When students are sharing information snippets like these, the arrangement of the F-formation depends on the former position. Figure 5 (left), shows the photographer (girl on the left side) standing on the slope where she had scanned the QR code as she gives the unlock code to her group. On the other hand, when students need to share more complex information, such as instructions or puzzles, they gather together to make sure everyone can hear clearly, a F-formation is consequently formed, for instance a circular arrangement, (e.g. Figure 5, right).

Figure 5. Verbal information sharing. Left: The photographer (on the left) is giving the unlock code to her team members; Right: The reporter is reading out a puzzle to others

On-device information sharing happens when members need to share information that is difficult to share concisely, such as images, maps or blocks of texts. In such cases students feel the need to look at the tablet by themselves, the device is then always in the o-space and students position themselves around the tablet. With a group of three, there are three possible formations:

1. The owner is in the middle holding up the device (Figure 6, left);
2. The owner is on one side, tilting the tablet towards the others (Figure 6, right);
3. The group stands behind of the owner, looking at the tablet over the owner's shoulder (Figure 8-E).

We observed the semi-circular formation more regularly in these situations. When two students are sharing a tablet, they usually stand in an L-shaped formation. When the information on the tablet requires significant reading time, others would take the owner's tablet for a moment.

Figure 6. On-device information sharing. Left: The owner is in the middle holding the tablet straightly; Right: The owner is on one side tilting the tablet towards the others.

Discussion within groups

We focus here on discussions to reach a consensus, such as when a group is figuring out the solution to a puzzle or discussing how to use a measuring instrument. This involves elements of suggestion and negotiation. From a F-formation perspective, we observed either discussions involving the whole group or a subgroup.

In *group discussions*, the three students are all involved in the joint activity. They are usually positioned in one of the two main F-formation arrangements: either the circular one or the semi-circular one. We observed the semi-circular arrangement when the discussion is based on the devices (Figure 7, left). Students talk to each other while checking the information on the tablets. The circular arrangement happens when students are discussing without using devices. In this situation, they are discussing face-to-face, and the circle becomes larger as discussion continues (Figure 7, right).

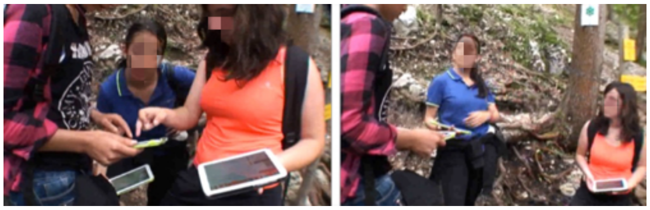

Figure 7. Change of F-formation during a discussion. Left: Students are in semi-circular arrangement when the discussion is around a tablet; Right: The arrangement changes to circular when discussing face-to-face

We observed students occasionally drifting a bit, or facing another direction while thinking. On other occasions, when they need to check something on a tablet, they would move towards the owner's tablet, the circle becoming smaller, and larger again once done checking. Students tended to shift between these two F-formations while discussing.

The *subgroup discussions* happen mostly when students need to deal with simple problems, such as where to go next and how to use the measuring instrument. In subgroup discussions, we mostly observed face-to-face and L-shaped formations.

GROUP DYNAMICS

Given the highly mobile nature of the activity, the structure of the formations changed rapidly. These dynamic transitions are particularly important in group work [1]. We present below the analysis of one sequence involving all the coordination mechanisms described previously and the transition from one to the next. Figure 8 shows the most representative formations.

> [00:00] [In group 2, the group found a QR code. Sophie (the photographer) goes ahead to scan it. David flips the cover of the tablet. Anna takes her tablet out of her bag. Now both are ready to input the unlock code to synchronize their tablet. (Figure 8-A, awareness.)]

Here the group is in triangular F-formation. David and Anna are aware of Sophie's action because scanning the QR code is part of the task. They know what Sophie is doing without getting closer to her. Hence awareness can be maintained in a triangular formation even at several meters of distance.

> [00:06] [Sophie gets the unlock code. She turns back facing David and Anna, and reads out the code to them. (Figure 8-B, verbal information sharing)]
>
> [00:07] Sophie: The code is 8OE.

Sophie reads the unlock code to the others in a triangular formation. The information is concise and can easily be shared verbally; she does not have to get closer to the others.

> [00:09] [David and Anna input the unlock code in their tablets.]
>
> [00:13] Anna: It doesn't work.
>
> [00:27] [Sophie starts moving slowly toward the others]
>
> [00:34] David: We shouldn't enter a space after the code. [getting closer to Anna to see her tablet]
>
> [00:40] [Sophie goes down the slope to form a circle with David and Anna, then looks at Anna's tablet. (Figure 8-C, awareness & regulation)]
>
> [00:40] Sophie: 8OE. [repeating the code.]

David and Anna are initially in a side-by-side formation inputting the unlock code on their tablets. As Anna notices a problem, David moves towards Anna to see what is happening on her tablet and provides a suggestion. F-formation changes from side-by-side to L-shaped to maintain awareness and facilitate regulation inside the subgroup. The same situation happens to Sophie. She is not aware of what David and Anna are doing, so she moves towards them. The group F-formation changes from triangular to circular. As she notices that Anna has issues inputting code, she repeats the code. This is a sign of regulation taking place, i.e., monitoring the task and providing assistance.

> [00:42] [Anna enters the code again. It works this time.]
>
> [01:04] [After synchronizing the tablet, Anna (the reporter) reads out the puzzle to two others.]

When Anna is reading out the puzzle to the group, they stay in the circular F-formation shown in Figure 8-C; this F-formation being suited for sharing information verbally.

> [01:15] Sophie: Let me see. [she takes over Anna's tablet]
>
> [01:20] David: Is one of the answers correct? [leans forward Sophie to see the puzzle (Figure 8-D, on-device information sharing.)]
>
> [01:22] Sophie: It's what they say in the puzzle.

In this part, even though Anna reads out the puzzle to two others, Sophie still grabs the tablet to read the puzzle by herself. This is a sign of complex information where sharing verbally is not enough. The change in tablet possession leads to a transformation of the F-formation from circular to semi-circular.

> [01:28] Sophie: Yes, yes, this one is the answer. [turns back and holds up tablet to show it to two others. (Figure 8-E, on-device information sharing & discussion)]
>
> [Sophie discusses the puzzle in more details.]

Figure 8. A sequence of collaborative behaviors and their corresponding F-formations. A: Sophie is scanning a QR code, David and Anna are watching (awareness); B: Sophie reads out code to others (verbal information sharing); C: David and Sophie move towards Anna to see her tablet (awareness & regulation); D: Sophie takes Anna's tablet (on-device information sharing); E: Sophie holds up her tablet showing it to the others (on-device information sharing); F: They are discussing the puzzle (discussion); G: David double checks the tablet (on-device information sharing); H: During the discussion, Anna suggests to move forward (discussion & regulation); I: Sophie asks David where to go next (regulation & on-device information sharing)

In order to share the tablet with the group, Sophie turns back and holds the tablet like a shared vertical display. The group forms an F-formation that we only observed before in large shared display environments: everyone is facing the same direction and sharing common focus on the screen content.

> [01:32] [Sophie turns to face the others and returns the tablet to Anna asking her to input the answer.]
>
> [01:34] Sophie: Try it to see if it is correct.
>
> [01:39] [Anna inputs the answer; the two others are looking at her.]

This is a sign of regulation by monitoring other's action, in the classical circular arrangement.

> [01:43] [They got the right answer and unlock the next puzzle. Anna reads out the puzzle again. Then they begin to discuss. (Figure 8-F, discussion)]
>
> [02:02] David: Wait, what is the third clue?
>
> [02:04] [Anna tilts the tablet towards David and he reads out the puzzle. (Figure 8-G, on-device information sharing)]

David and Anna change F-formation to corner-to-corner, the group is still in roughly circular formation. The F-formation is changing based on the sharing of devices.

> [02:16] [Discussion keeps going. Now they don't need the tablet, the circular F-formation becomes larger. Sophie and David also exchange their position while they are discussing. (Figure 8-H, discussion)]

When students are suggesting ideas, discussing solutions, they do not stay in position, moving or turning a bit. The movement is always surrounding the o-space, and always coming back to a circular formation.

> [They spend a while discussing, but do not manage to figure out the answer.]
>
> [03:49] Anna: We should keep on going. We may find clues at the next location.
>
> [03:50] David: Yes.
>
> [03:51] Sophie: I agree.
>
> [They decide to keep on moving. (Figure 8-H, discussion & regulation.)]

Anna regulates the group's activity by proposing another strategy. Regulation happens during the discussion.

> [03:52] Sophie: What does the map say?
>
> [03:54] David (the explorer): It doesn't say anything. [He shows tablet to Sophie. (Figure 8-I, regulation & on-device information sharing.)]
>
> [03:57] Sophie: So where we should go?
>
> [03:58] David: Keep on going in the same direction, we will see.
>
> [04:01] [They leave the area.]

In Figure 8-I, Sophie is regulating the group activity by figuring out the next location. She and David are sharing the tablet forming an L-shaped F-formation. Anna is not involved in their action; she is in the r-space of the F-formation.

Table 2 and 3 present a synthetic view of the dynamic of F-formations, their occurrence, transition and duration for this particular sequence.

Time	Sub-activity/action	Formation	Duration
00:00	Sophie scans QR code	triangular	27s
00:06	Manual synchronization		
00:27	Sophie moves towards two others	transition	
00:32	David moves towards Anna	transition	
00:34	David looks at Anna's tablet	Dyad L-shaped	6s
00:40	Sophie joins in two others	circular	35s
01:04	Anna reads out the puzzle		
01:15	Sophie takes over tablet	transition	
01:20	Group discussion	corner-to-corner	12s
01:28	Sophie turns back and holds up the tablet		
01:32	Sophie turns back and returns the tablet	transition	
01:39	Anna inputs the answer	circular	23s
01:43	Anna reads out the new puzzle		
01:58	Group discussion		
02:02	David wants to check the puzzle	transition	
02:04	David and Anna are sharing the tablet	L-shaped in circular	12s
02:07	Group discussion		
02:16	Sophie start to move	transition	
02:22	Sophie stops; group is discussing	corner-to-corner	18s
02:40	David starts to move	transition	
02:44	David stops; group is discussing	circular	68s
03:49	Anna suggests to move forward, others agree		
03:52	Sophie wants to see the map on David's tablet	transition	
03:54	Sophie and David are sharing a tablet	Dyad L-shaped	7s
04:01	Groups leaves the site		

Table 2. Timeline of the activity

F-formation	Number	Duration	Percentage
L-shaped	3	25s	11.4%
Triangular	1	27s	12.3%
Circular	3	138s	62.7%
Corner-to-corner	2	30s	13.6%

Table 3. Comparison of the F-formations observed.

DISCUSSION ON THE STUDY

On the impact of manual synchronization

Due to the lack of network in the mountain, and to increase robustness, we designed the game without relying on any communication between tablets. Based on the video analysis, we found that manual synchronization had mostly an impact on groups' arrangement. Triangular formations mostly happened when the reporter was scanning the QRcode and then was facing the two others group members to share the code. The absence of automated information sharing also forced players to maintain awareness of the group activity verbally and physically, causing changes in F-formations: transition from triangular to circular organization for instance. However, manual synchronization did not impact the activity and task performance. After students became familiar with the activity, passing and inputting codes only lasted a dozen of seconds. Besides that, we also observed that instead of taking manual synchronization as an annoying chore, students enjoyed sharing code. The code owner seemed to have a sense of achievement of passing code to others, and the two others were excited on what would happen after they inputted the code. Opposed to our expectations, the manual synchronization appeared to increase engagement in the activity and let students have a stronger feeling of progress than they would have with automated synchronization.

On maintaining awareness in a highly mobile and distributed environment

The various roles introduced in the application, with game content specific to each, had an impact on social behaviors and coordination mechanisms. This approach impacted awareness with players needing engage with others to get some specific information they did not have. Environmental constraints and the highly mobile nature of the game also played a role in the lack of awareness and influenced the changes in formations. For instance, we observed creation of short-lived subgroup formation to check the tablet of another player, or transitions to semi-circular arrangements.

On the impact of devices size

We did not observe any impact on F-formations and coordination mechanisms linked to the use of the larger tablets. We handed these devices to two explorers; they used the map on the device for guiding their group.

IMPLICATIONS OF THE STUDY

We set to investigate how mobile devices would be used in a collaborative mobile game through the lens of F-formations. From our analysis of participants' mobility, positions, orientation, and coordination mechanisms, we derive the following implications.

Better support for regulation

Shared indicators of progress on group objectives, and of individual progress within the group, could have improved players' coordination, and eased coordination. For example, showing at which stage the whole group was could have helped players move to the next steps faster. Or showing the amount of earned badges could both improve self-esteem and encourage players in sharing and gaining expertise. But indicators supporting regulation should be designed with care not to decrease existing social interactions and engagement.

Better support for complex information sharing

While sharing snippets of information such as unlock codes or map positions was no problem. Sharing more complex information was challenging and frequently led to new group arrangements to cope with the lack of shared ground. In such situations three people focusing on a single tablet is burdensome and impedes collaboration. There is a need for tools enabling collaborative interaction with complex information in mobile conditions.

For instance, in semi-circular formations, we could use proximity to enable information transfers between tablets, as proposed by Marquadt [25]. We could also enable the duplication of screens for a moment, or enable a focused/zoomed-in mode so that information is more readily visible to people in a circle.

Focusing on transitions between F-formations

Most of the arrangements we observed were only stable for short amounts of time. When designing tools to better support collaboration, rather than capturing given F-formations, emphasis should be given to changes between arrangements. For instance, the transition from one formation to another could be pro-actively managed on the devices by suggesting which device configuration would be most useful. Another possibility would be to let users to maintain the state of a previous configuration even though the arrangement has changed.

Subtlety and control in proxemic interaction

Leveraging proxemics to support users' interactions in context aware systems is promising, but should be treated with care in mobile conditions. Especially in outdoor conditions, the cost of implicit adaptations might not be worth the benefits. We observed many situations in which the arrangements of the participants were similar but the high level activity required different information and devices configurations.

Better representation of formations and their dynamics

Throughout our analysis we struggled to find a way to systematically code and represent micro-mobile behaviors and the transitions between F-formations. We only introduced tablets in our diagrams of F-formation and small multiples (Figure 7) as a first step in improving the notation of F-formation and mobility.

We believe that progresses are needed in the development of a visual language describing device use in F-formation, and in transitions between them. This would enable more systematic annotations and the ability to quantify formations more easily. Elements whose representation would help analysis include:

- Device states (e.g. active, on-hold, folded away);
- Mobility within a group as people maintain the formation (e.g. rotation, shift, or expansion/reduction of the arrangement); or
- Transition from one arrangement to another.

Finding better ways to represent such dynamic behaviors would also help develop better models of collaboration, and create better computational representations of the activity, e.g., state machines of mobile collaboration.

CONCLUSION

We focused this analysis on the relationship between participants' F-formations, the way they used their devices, and the coordination mechanisms. In such mobile conditions we observed very dynamic spatial arrangements of groups. The F-formations could be maintained while the group moved (e.g. rotating, drifting, getting closer or further away), or changed to form new F-formations more suited to the ongoing task. While some coordination activities were strongly associated to an F-formation and a specific type of device usage, e.g. the verbal transmission of codes. Other activities like sharing complex information, required to considering the dynamics of collaboration rather than a static scene. Although the game design influenced the interactions between participants, our analysis should be relevant to most outdoor collaborative activities.

Finally, we observed a need for more powerful tools to analyze collaboration with mobile devices in mobile situations. New programming tools are also needed, first to model multi-device coordination, and then to support the development of multi-device collaborative interactions, especially when large shared displays are not available.

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