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VISUALISATIONS FOR LONGITUDINAL PARTICIPATION, CONTRIBUTION AND PROGRESS OF A COLLABORATIVE TASK AT THE TABLETOP

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Visualisations for longitudinal participation, contribution and progress of a collaborative task at the tabletop

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Abstract: One of the challenges for facilitators in collaborative work is that they typically see only the final product of a group's interactive work. This is a problem as it means that the role of each individual may be hard to determine. This paper proposes a set of visualisations which aim to give teachers insights into longitudinal participation of each group member, an indication of the extent of each learner's contribution and the building process of the group product in terms of overall activity towards a good solution. We exploit the affordances of tabletops to capture the data to infer these visualisations. We evaluate these by assessing whether facilitators could answer key questions about these aspects. Key contributions of the paper are the design of these new visualisations, results of their evaluation and the implementation of a tabletop concept mapping application which was carefully designed to both support collaboration and capture of the history of the collaborative process.

Introduction

One of the challenges for teachers and facilitators in collaborative learning contexts is that they typically see only the final product of a group's interactive work (Race, 2001). This is a problem as it means that the group work itself and the relative contribution of each individual to the group product may be hard to determine. This problem can dissuade teachers from using group work. Yet, there is acknowledged value in collaborative knowledge creation, where learners create artefacts, like tools, symbols, concepts, texts; making use of processes like grounding and negotiation (Paavola & Hakkarainen, 2005). Such artefacts can capture the common understanding of subject matter and innovative ideas of the group. One method to facilitate discussion of a content area is through the construction of concept maps (Stahl, 2006). We have chosen this well studied technique for our work as it has proved useful in education for externalizing knowledge; concept maps can be considered as external reflectors of internal learner's knowledge (Tergan, 2005).

Interactive tabletops provide a new way to support collaborative tasks because they permit face-to-face interactions between individuals and, at the same time, present information to the group through a shared device. However, they also introduce new challenges, both at the technical and social levels. Our research explores the affordances and challenges of supporting groups to externalise their knowledge of a domain using a tabletop interface, and by making the mapping process visible to learners' teachers.

We present a set of mirroring visualisations we have designed for a small group of users building an artefact, such as concept map, using a multi-touch tabletop. These visualisations provide a mirror of the learners' actions (touch/verbal participation radar), an indication of the extent of each learner's contribution (contribution chart) and the evolution of the artefact through its building process (evolution diagram) in terms of complexity of the group product. We aim to determine the visualisation features that give useful information about the collaboration at the tabletop. These visualisations aim to summarise and make visible the actions of the group to help facilitators detect problems in group interaction.

We evaluated the visualisations by assessing whether teachers could answer key questions about *participation, contribution* and the *process* of the collaborative activity of the group. Our key contributions are the design of these new visualisations, the implementation of a tabletop application for concept mapping and an evaluation which indicates that teachers can answer 4 of the 5 key questions related to longitudinal equity and quantity of participation, contribution of group members and collaboration.

The remaining of this paper is structured as follows. In the next section, we present our tabletop application for concept mapping and the design of our visualisations. Then, we describe the evaluation. We conclude with reflections on the visualisations and our research agenda.

Related work

Several researchers have explored how to exploit the potential of digital tabletops in educational contexts. Morgan and Butler (2009) proposed settings that encourage learning with high levels of collaboration at multi-touch displays, grounded in theories of Situated Cognition. They designed systems for storyboarding, group concept mapping and building phonemic awareness between dyads. Busine et. al. (2007) describe use of interactive tabletops to support group creativity through the construction of mind-maps. Additionally, Sugimoto et al. (2004) show how tabletops, used in conjunction with personal devices, can support discussion and negotiation in face-to-face collaboration with learners manipulating private and shared objects.

Research in tangible tabletops has also explored their affordances for detecting interference in collaboration (Falcao & Price, 2009), analysing division of labor (Jermann et al., 2009) and to aid mind-mapping (Oppl & Stary, 2009). However, a recent study failed to show significant learning benefits at a tabletop, compared with working on a single desktop computer (Do-Lenh, Kaplan, & Dillenbourg, 2009). In this study, those using the multi-touch tabletop tended to work in parallel and had difficulties drawing all the pieces together at the end of the trial. This highlights the need for an effective support at the tabletops.

There has been considerable work exploring the importance of group visualisations to externalise the activity of groups and, in many cases, to reveal relationships between observable patterns and the quality of the group work. Erickson et al. (1999) created the *social proxy,* a visualisation of chat sessions of a group. This resulted in improved collaboration and better support for people to learn how to collaborate. Donath (2002) went a step further, showing the nature of participation in a visualisation of group activities of the group members. In (Kay, Maisonneuve, Yacef, & Reimann, 2006) a set of visual representations of long term activity of groups was designed, based on a model of small group teamwork. These present salient aspects of group activity, including the level of participation, interaction between members and leadership. The *Narcissus* project introduced a visualisation of group activity which enables a user to navigate through to see the detailed evidence that contributed to each part of the group work (Upton & Kay, 2009). In addition, Janssen et al. (2007) explored the effects of visualisation of participation in groups of learners. They found that visual representations of the group can be useful for coordination and regulation of group members.

The collaborative learning environment

We now describe the context of our work to design and then evaluate visualisations of group activity in a collaborative concept mapping system. We used the tabletop system called Cmate (Martinez, Kay, & Yacef, 2010). This was designed for use in two stages: first, an individual stage, where each group member creates their own concept map; and a group stage, where they come together to create a collaborative map. This approach was also used by Engelmann & Hesse (2010) with the difference that we provided a shared tabletop for the group phase. For the individual stage, participants used CmapTools (Novak & Cañas, 2008), a desktop-based concept mapping application. These individual concept maps are used to extract the personal vocabulary of concepts and links, and make them available to the learners in the group stage at the tabletop. Importantly, this stage enables each individual to focus on the cognitively demanding task of externalising their knowledge, by drawing their individual maps in private. Then, they come to the tabletop to compare and discuss their different perspectives of the subject matter and create a collaborative concept map (left of Figure 1). In this stage, participants can use the concepts and links they previously included in their individual artefacts and relate them with other participants' pieces of map to build a new mutually accepted map.

We designed Cmate to maintain the collaboratively created group map as well as one layer per user, showing their individual map contributions. The basic actions that learners can perform are: creating a concept, drawing a circular outline with the finger; creating directed link, drawing a line in between two nodes; moving concept/link, touching the node and dragging it with the finger; deleting node, moving the node to off-screen; and editing node word, double tapping a node and modifying the word through a virtual keyboard.

The tabletop used in the studies had a 46-inch LCD touch screen with a display resolution of 1920x1080 pixels, offering enough space for up to four participants. The tabletop hardware can detect multiple touches at a time, but cannot recognise which user is providing an input. For our study, every touch on the tabletop was logged and the entire sessions were videotaped using a fixed camera above the tabletop and another camera at one side. Sound was recorded with individual headphones worn by each participant.

In order to aid facilitators, it is crucial to know who is doing what and what has been done on the tabletop. Morgan and Butler (2009) proposed four approaches to track the contribution made by each person at

Figure 1. Tabletop concept mapping. Cmate in action with 4 people, 2 at each long edge of the table (*left*). Personal spaces for tracking individual participation on the tabletop (*right*).

the tabletop: by defining fixed workspaces where each person should work; by claiming "ownership" on the objects; establishing a production line, in which each object is sent to a task bar of each person at least once to work on it; or by defining roles, in which each person is allowed to do just some specific actions. We created a different approach to track individual participation. We provide a moveable circular personal area on the tabletop for each participant. Users can *initiate* all actions just inbounds of these areas. To perform actions on the concept map, participants move their personal area above the target element and then perform the actions. This technique increases the load of touches on the tabletop but gives personalised concept/linking word lists for creating nodes, orients the elements towards the user and also supports tracking of all the touches that each participant does (*right* of Figure 1). For the position of learners around the tabletop, it has been shown that this has an effect on the division of labor spontaneously adopted by the learners (Jermann, et al., 2009). Consequently, we had participants in pairs along both long sides of the rectangular tabletop. This gave each participant equal opportunity to participate, access the resources, and perform the full range of actions. Where the group had three participants, we had to settle for a slightly less ideal spatial disposition.

We ran the study with 10 participants in 3 groups, each of 3 or 4 participants. All groups were asked to build concept maps individually at a desktop and then a group map at the tabletop, on the topic: *how does the water cycle work?* First, participants were introduced on the concept mapping technique. Then they read a two page text on the water cycle and were asked to draw an individual concept map. The participants could use any terms, any number of concepts in their maps and were not restricted to follow any hierarchical arrangement of concepts. However, we provided a list of suggested words, extracted from the instructional text. After completing their concept maps, the group was asked to generate a group solution concept map at the tabletop.

Design of visualisations

We now describe the four visualisations we designed: the Touch/verbal Participation Radar, the Map Contribution Chart and the Map Evolution Diagram.

Touch/verbal participation radar

This first visualisation was strongly influenced by the circular social proxies of Erickson (1999). We also drew on previous work in collaborative learning, with a focus on the learning impact of the equity of oral participation and decision making (Bachour, Kaplan, & Dillenbourg, 2010). From this, combined with the procedure to study levels of participation on the tabletop proposed by (Harris et al., 2009), we chose two dimensions: the physical events on the tabletop, measured in terms of the quantity of touches; and time of verbal participation, measured in seconds. This gave a pair of radars: the radar of touch participation (see Figure 2, red shaded radars) and the radar of verbal participation (Figure 2, blue shaded radars).

The time window for each visualisation covers the previous 5 minutes of activity. So for example at time 15, the radars show the number of events between the 10 and 15 minutes. Each coloured round marker corresponds to one learner at their circular personal space: orange, yellow, green and purple for participants 1, 2, 3 and 4 respectively. The position of these markers indicates the level of participation; the closer the marker is to the centre, the less active they were in the last five minutes.

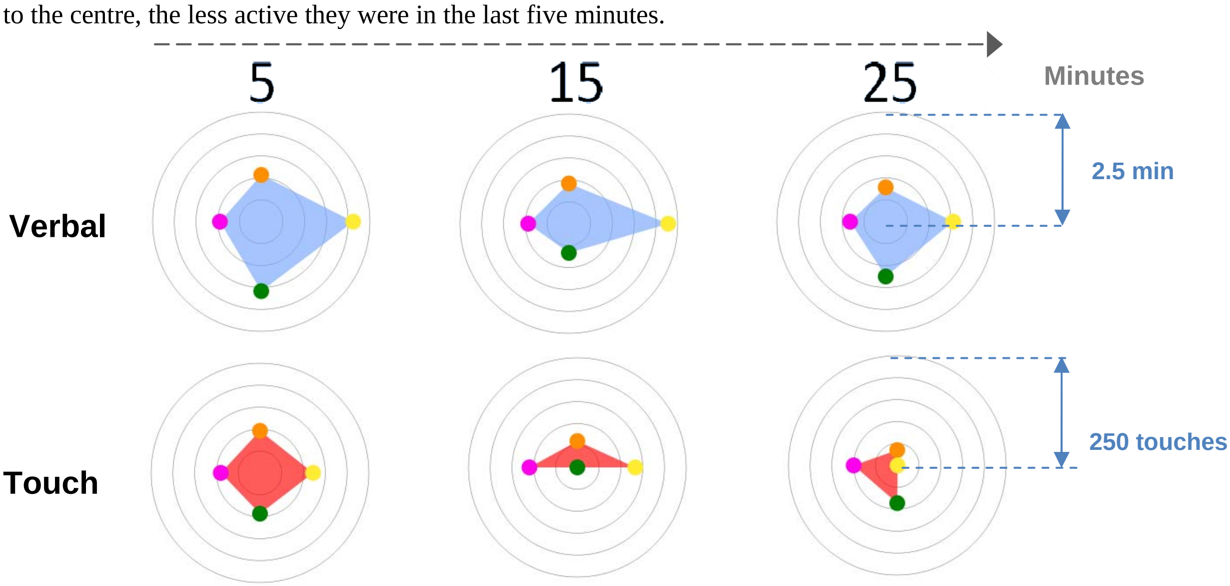

Figure 2. Participation radar. (*left*) First five minutes. (*center*) Between minute 10 and 15 (*right*) Between minute 20 and 25.

The shape of the radars depicts the symmetry of activity, an important aspect of collaboration (Dillenbourg, 1998). For example if there are 4 learners, a perfect, symmetric square indicates that the number of touches or the talking time are the same for each learner. In the radars shown at the right of Figure 2 (at time 25), we can observe that the participant corresponding to the yellow marker (at 3 o’clock) did not touch the tabletop at all but did most of the talking. This could possibly be a clue that the participant was influencing the actions of others by talking but, without further information, could equally mean that he/she was engaged in a conversation that had nothing to do with the task.

Contribution Chart

Concept mapping has the potential to drive collaboration because it provides an externalisation of each learner’s different perspectives (Tergan, 2005). For this reason, we propose the contribution chart, which shows the proportion of actions from each team member that resulted in a change in the collaborative artefact. The actions that add substantial knowledge to the map are the creation, editing and deletion of nodes. The map contribution chart gives an overview visualisation of the proportion of these actions that each participant made. Figure 3 shows three of these for the same group, at 5, 10 and 20 minutes, and also shows the total number of concepts and links created in the group artefact. One of the ideas we had in mind here is to show if any of the participant’s perspectives is leading the processing of the concept map or if they are equitably contributing to it. This visualisation complements the radar of participation by indicating the amount of the activity that has indeed made a substantial impact on the group artefact. For instance, the first chart in Figure 3 (at time 5) shows that one person (in pink at the top) contributed about half the concept map’s elements, two people (green and yellow) contributed a quarter, and one (red, at the right) much less than the others. At time 10, however, we can observe that the other three participants increased their contribution greatly (especially yellow and red), and later on (at time 20), the same participant (pink) contributed the most again.

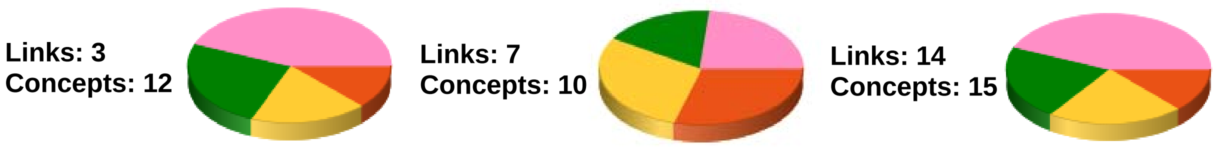

Figure 3. Map contribution chart. (*left*) After 5 minutes. (*center*) After 10 minutes. (*right*) At after 20 minutes.

Evolution Diagram

The third visualisation is the Evolution Diagram (Figure 4). This shows the key temporal events in the group concept map. The vertical axis shows the number of propositions made to the group concept map and the horizontal axis time represents the time in minutes. The graph has two lines: i) the upper blue line includes coloured circles indicating addition of each proposition; ii) the lower red line shows the number of propositions that match those in the master concept map (created by the teacher). So, the upper line shows the total number of propositions and the lower line shows how many of these match the expert map. To calculate the distance between the group map and the master map, we use an automatic open-ended concept map scoring technique based on Pathfinder associative networks (Taricani & Clariana, 2006).

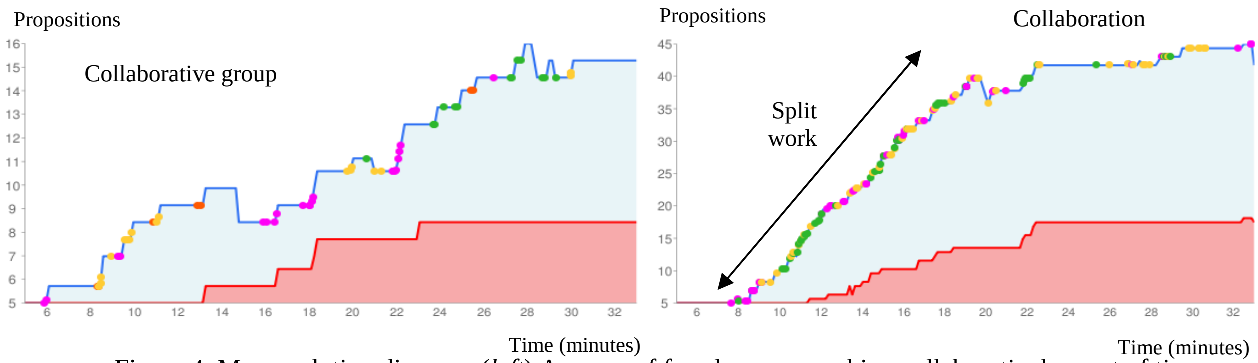

Figure 4. Map evolution diagram. (*left*) A group of four learners working collaboratively most of time. (*right*) A group of three learners who divided the work during the first 20 minutes.

In the upper line, the coloured markers represent the user who added the proposition(s). In Figure 4 (*left*), the visualisation shows that the group has worked for more than thirty minutes and has created 16 propositions. Observing the purple markers (User 4) we see that this user created more propositions that were present in the master map, as the purple markers coincide with signs of progress of the group map towards the master map. In contrast, the map evolution diagram on the right shows that, up to Minute 20, this group added many links to the map but these actions did not result in any matching with the expert map, suggesting that users were working independently. Note that, in this visualisation, the similarity with a master concept map, is not used to score the group map but just as an indicator of how many of the group's propositions match those in the master map.

Evaluation

Our aim here is to answer a set of questions which assess the usefulness of the information that our visualisations can provide about equity of participation, quantity of participation, collaboration and equity of intellectual contribution of the members of the group (Dillenbourg, 1998; Stahl, 2006) and about the process of the map construction in terms of contribution and actions of the group members. We expect that the support offered by our visualisations should make visible facets of the collaborative process to facilitators and hence lead to improve the feedback they can offer to the group. Specifically, we aimed to evaluate five hypotheses. These are that the visualisations provide useful information about:

- (H1) the equity in the roles and participation of group members;
- (H2) the amount of participation of the group members;
- (H3) the group in terms of collaboration;
- (H4) the equity of intellectual contribution of group members;
- (H5) the creation process of the map in terms of the relative contributions of group members and the effectiveness of the group work.

To assess these hypotheses, we ran evaluation sessions with five different experienced facilitators. We provided them with a set of the visualisations generated from the tabletop sessions of two groups: A and B. These visualisations included: snapshots of the Radars of Participation and Contribution Chart corresponding to the minutes 5, 10, 15, 20, 25 and 30, the Evolution Diagram and the final group concept map. We also provided the final maps, both individual and collaborative. Then, we invited the facilitators to respond a set of questions regarding to the equity of participation, quantity of participation, the collaboration, the equity of intellectual contribution of the group members and the usefulness of the visualisations to depict the creation map process in terms of contribution and group work. These questions correspond to each hypothesis posed above and they were answered on a 7-point Likert scale in which 1 represents strong disagreement and 7 strong agreement. We allowed them to mark a question as "unanswered" if the visualisations did not give enough support for a decision. We asked the participants to justify their responses and state which visualisations they used.

Inspection of the session videos

As a basis to compare the information inferred by the facilitators from the visualisations, we inspected the video recordings of each group's session. We describe them now.

Group A was a highly collaborating group right from the start. They focused from the very beginning on working collaboratively and they built the concept map as a group. They never divided the task; they all discussed every single part and action each group member performed. They worked in parallel for brief periods but never loosing awareness of others. They added key concepts and links, and tried to eliminate redundant concepts by "generalizing" them to come up with a clearer map. It is really important to point out that before finishing the trial they realized that the concept map shape should be a circle, given that the water cycle is indeed one. Notably, in the individual maps, none of the participants drew a cyclic map.

Group B worked independently, then started collaborating in the last half of the session. They started by adding many concepts and links to the tabletop, explaining and giving brief comments to the others about their actions, which concepts they considered important and asking if they had already added specific concepts that they may use. The concept map at the tabletop, as shown *left* of Figure 5, is itself a visual aid because it highlights the different propositions added by each participant. This feature proved to be really useful for this group. They divided the task and worked in parallel without collaborating until minute 20. At minute 21 one member of the group said: "*your area has more green colour, mine is purple and yours more yellow ... we really came up with three distinct parts. There should be more links between them*". They tried to collaborate after minute 20. The evolution diagram shows this change in the group's behaviour (*right* of Figure 4). Then they worked together to decide which links could best connect the different three main areas of the concept map. However, they ran out of time and the final map was complex and was a poor response to the task.

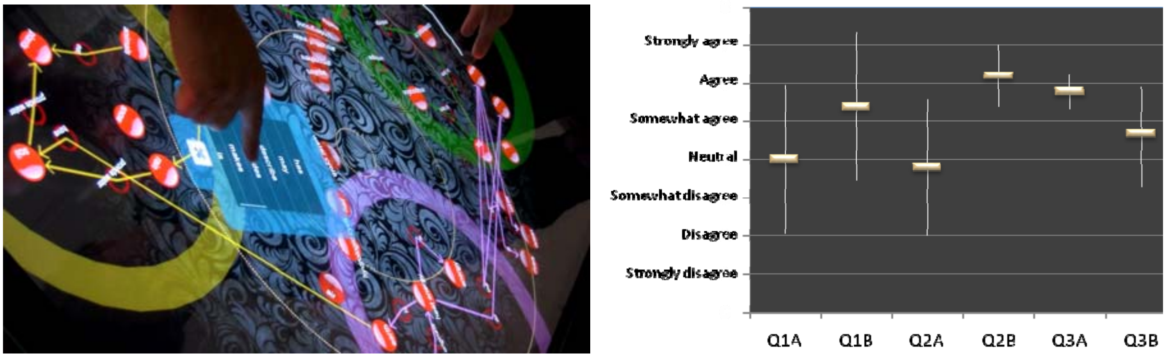

Figure 5. (*left*) The colored links of the map as a visual indicator of contribution itself. (*right*) Overview of the results of the questions related to: equity of participation (Q1A for group A and Q1B for group B), quantity of participation (Q2A, Q2B) and collaboration (Q3A, Q3B)

Results

All the facilitators were able to easily understand the visualisations and complete the questionnaire without difficulty. Participants were highly engaged in the inspection of the visualisations, and expressed their thoughts verbally, permitting the experimenter to take note of which visualisations influenced their comments and answers about the groups of learners.

The facilitators never had access to the videos nor were they given a summary of what happened. They inspected the visualisations carefully before giving an answer to each posed question for both groups A and B. To look for an explanation of the acceptance or rejection of each hypothesis, we validated the responses to the questions at two levels. Firstly, we refute a hypothesis if its respective question could not be answered by 2 or more facilitators. This filter refutes a hypothesis if the facilitators could not find evidence from the visualisations to give an answer. Then, the next step was to ascertain whether their answers matched the observations of video recordings of the group sessions. Table 1 summarises the questionnaire responses. Columns Q1, Q2 and Q3 were used to generate the graph of Figure 5 (*right*). Table 2 summarises which visualisations the facilitators used to give an answer to each question.

(H1) *These visualisations provide useful information about the equity in the roles and participation of the group members*. The focus of this hypothesis is to assess whether the visualisations portray the symmetry of participation of the group members (Dillenbourg, 1998). Four of 5 facilitators used the radars of voice and touch to answer this question (see Table 2). For group A, the participation was equitable but one participant dominated most of the talking. This can be observed in Figure 2. In Figure 5 (*right*, see Q1A) we notice that in general the responses of the facilitators did not confirm that the group was neither symmetric nor asymmetric. In general, the facilitators judged group B to be symmetric (see *right* of Figure 5, Q1B). In fact, the video recordings show that group B members worked in parallel and they did not influence each other. Thus we accept the usefulness of the radars of physical and audible participation based on the direct observations of the facilitators who remarked that the coloured shaded radars and the concentric circles were useful to quickly detect if the participation of a group was symmetric or not.

Table 1. Summary of the questionnaire responses. Columns: questions asked to the evaluators. Rows: AVG: Average of 7-point Likert scale answers. STD: Standard deviation

Group A	Q1	Q2	Q3	Q4	Q5
	equity	quantity	collaboration	Contribution	process
AVG	4	3.8	5.8	6	6.25
STD	1.95	1.8	0.45	- *	0.5
Lickert	neutral	neutral	agree	Agree	agree
Group B					
AVG	5.4	6.2	4.5	6	6.25
STD	1.95	0.8	1.2	- *	0.5
Lickert	agree	agree	somewhat agree	Agree	agree

(H2) *These visualisations provide useful information about quantity of participation of the group members*. The focus of this hypothesis is to assess if the visualisations depict the quantity and equity of participation in the group members; therefore, it is related to H1. However, in this case, all the facilitators used the Contribution Chart in addition to the radars of Participation and the Map Evolution Diagram to answer to this question. Group A was reluctant to do physical actions compared with Group B focusing more on the discussion and negotiation of each proposition to be created or each element to be deleted. By contrast, Group A divided the task and added a large number of propositions. Indeed, the facilitators strongly agreed that in general group B members participated in an equitable way. For group A they noticed that the members did not perform many actions and some evaluators signaled that they were talking too much and physically working very slowly (see *right* of Figure 5, Q2A and Q2B). Therefore, we accept the usefulness of the map Contribution Chart in conjunction with the Radars of Participation and the Evolution Diagram because they gave insights to facilitators to size the quantity of participations of the group of learners.

(H3) *These visualisations provide useful information about the group in terms of collaboration.* The focus of this hypothesis is to assess if the visualisations can offer hints to the facilitators to indicate whether the group was collaborative or not. To answer the question related to this hypothesis, the facilitators used all the visualisations including the final product map. All the evaluators agreed that group A was collaborative, even though their final product was a small concept map. Moreover, the facilitators considered that in this group the participants interacted with others based on the high levels of talking observed in the verbal radars and the sparse *add link* events shown in the Evolution Diagram (*left* of Figure 4). In the case of Group B 3 of 5 facilitators concluded that the group divided the work most of the time given the low levels of talking and the creation of many links in a short time window (*right* of Figure 4). Moreover, the facilitators agreed that the group tried to collaborate in some way before the end of their activity (see *right* of Figure 5, Q3B). We can conclude that the visualisations aid in the perception of various forms of collaboration; however, these results should be confirmed with more case studies.

(H4) *These visualisations provide useful information about the equity of intellectual contribution of the group members*. The purpose of this hypothesis is to assess if the facilitator considers that the content of the concept map reflects intellectual contribution of each member of the group. We refute this hypothesis given the fact that just one of the five facilitators responded to the question related to it (see Table 2). All of them tried to infer intellectual contribution based on the Contribution Chart and the Radar of Voice participation, but afterwards, they concluded that it is difficult to infer on intellectual contribution without knowing the content of the utterances. Indeed, new knowledge is created through the content of the discourse of the group (Stahl, 2006).

(H5) *These visualisations provide useful information about the creation process of the map in terms of the relative contributions of group members and the effectiveness of the group work*. We validate this hypothesis by the direct answers to the corresponding question. All facilitators somewhat agreed with the usefulness of the visualisations because they provide information about the process of map creation in terms of the physical and verbal actions.

Overall the facilitators could answer 4 of 5 questions. These give insights into the usefulness of such tools for monitoring the collaborative situation at the tabletop even when the facilitator has the opportunity to observe the actions of the group in situ. Thus, the visualisations aim to complement the qualitative function of facilitators by providing quantitative insights about the group. Even when the results match well with the qualitative observations on equity, quantity, and the most important, the presence of real collaboration, the goal of the visualisations is to aid the qualitative results, not to take its place (Stahl, 2006).

Table 2. Visualisations that were used for the facilitiators to answer each question

	Evaluators				
Questions	1	2	3	4	5
1	Radars - Chart	Radars – Chart	Radars - Chart	Radars - Chart	Radar (t) - Chart
2	Radars - Chart	Radars – Chart	Radars	Evolution map	Radars - Chart
3	Final product - Evolution map	Radars – Chart	Radars	Final product	Radars
4	X	Chart	X	X	X
5	Radar (v) - Evolution map	Radars	X	All	Radars

Conclusion

We have presented a set of visualisations that externalise the activity of groups working together at the tabletop to build a group artefact. The Participation Radars provide a mirror of learners' actions both verbal and physical. The Contribution Chart gives an indication of the extent of each learner's contributions to the group artefact. The Evolution Diagram depicts the building process of the artefact relating this to a master artefact and with each participant's contribution. These visualisations each trace different aspects of a group, and the combination of the three visualisations with the final group artefact can help the facilitator better understand the nature of the collaboration in order to make better decisions regarding to the guidance of the group of learners.

The ultimate goal of this line of research is placed in the context of fostering co-located collaborative knowledge building tackled through the study of the digital footprints of the learners. Future research will focus on evaluating these visualisations outside the laboratory, in real learning contexts. We also will explore ways to identify the significant patterns of interactions. Given the complexity of group interactions, we believe that it is really important to link the quantitative indicators with other forms of empirical assessment of collaborative accomplishments.

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