Unpacking traces of collaboration from multimodal data of collaborative concept mapping at a tabletop

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Abstract: During collaborative student work, teachers aim to support groups effectively and ensure that each group member can contribute at some level. Analysing the final product of group work does not reveal individual contributions or the collaborative process. This research investigates indicators of collaborative learning, captured by a novel tabletop environment, which can provide real-time information about the ongoing collaborative work. This can enable teachers to direct their attention more effectively. This paper reports findings from a case study on collaborative concept mapping. Five triads of university students engaged in a collaborative activity on the topic of human nutrition. The variables, level of participation, symmetry of participation, similarity of previous knowledge, knowledge contribution, transactivity, interaction and knowledge creation, were used to describe the collaborative process. Results offer promise for transforming this collaboration data to give informative feedback to teachers and support collaborative learning.

Introduction and related work

Research suggests that collaborative work can promote active participation of students and improve learning. It can enable students to, consider alternative ideas, negotiate shared knowledge and move more readily from receiving knowledge to constructing understanding and creating new artefacts (Paavola & Hakkarainen, 2005). Advantages of face-to-face collaboration, compared with other ways of learning include that learners can communicate continuously, move between individual and group work, and be more productive in completing their tasks (Olson, et al, 2002). However, students working in groups often do not naturally collaborate to reach common goals. To make collaboration effective, groups often close teacher support. In traditional classrooms, teachers can often only assess the final product, which does not reveal individual contributions. Nor does it give the opportunity for providing feedback at the time it was needed. Teachers need real-time information about which groups and group members need their attention to provide such support.

Concept maps can be used as social artefacts through which students communicate (Roth & Roychoudhury, 1993). Their high degree of explicitness makes concept maps an ideal vehicle for exchanging ideas for collaborative constructing knowledge. It has been reported that students who collaboratively generated concept maps achieved higher scores than those who constructed theirs individually (Okebukola, 1992). When concept maps are generated collaboratively they become shared social artefacts that elicit existing and missing connections and spur discussion among students and teachers. Both, concept maps and collaborative learning, have been found to have educational benefits. Combining the two could produce synergistic beneficial effects.

Interactive tabletops are promising to improve collaborative learning and there is growing interest in how they can enhance classroom activities. The promise of interactive tabletops is that they offer a tangible shared space that can enrich collaborative work by providing access to digital content. However, existing tabletops do not automatically capture and analyse collaborative interactions between students in real-time to support teachers' guidance. The rich content that can be captured by these devices can offer teachers and researchers new opportunities to inspect the collaborative process through tools that help recognising behaviour patterns and analyse how learners collaborate (Medina & Suthers, 2008). A number of researchers have explored the potential of interactive tabletops to support collaboration and learning. Rick et al. (2009) analysed the effects of the tabletop environment on students' participation. They found that technical aspects such as software design, students' physical arrangement or the hardware features affect groups' collaboration and their time to complete tasks. Evans et al. (2010) presented their work on tabletops that support mathematical skill acquisition and suggested that interactive tabletops make it possible to track the students' actions and provide real-time feedback. Martinez et al. (2011d) reported initial work on extracting patterns of physical interaction that are linked to the strategies followed by high achieving groups of learners.

This research goes beyond previous work by describing findings of a case-study that aimed to a) implement a tabletop as a shared space for group collaboration where students can integrate their *individual ideas* and create a *shared artefact*, and b) capture student behaviour during the group activity in a pervasive manner to provide teachers with real-time information about the ongoing collaborative process. The contribution of this paper is the novel approach to automatically exploiting captured audio and application traces of students' activity at a tabletop to summarise and provide indicators of the collaborative process.

Method

The learning environment captures the interactions of users with the tabletop, their verbal participation and the representation of their knowledge in the form of concept maps. The research question this study addresses is: What measures can be automatically captured from a tabletop learning environment that complements the empirical observations made by a teacher?

Tabletop learning environment. The interactive tabletop offers a comfortable space for up to four learners and recognises input from each user through an over-head depth sensor that tracks learners' position (Martinez, et al., 2011b). This system allows direct-manipulation of the virtual objects on the tabletop and tracks who is touching what in a pervasive manner. Discussions are recorded through a directive microphone array that can identify when each learner is speaking. For this study, only the frequency of verbal contributions was used. Figure 1 shows the main parts of the learning environment.

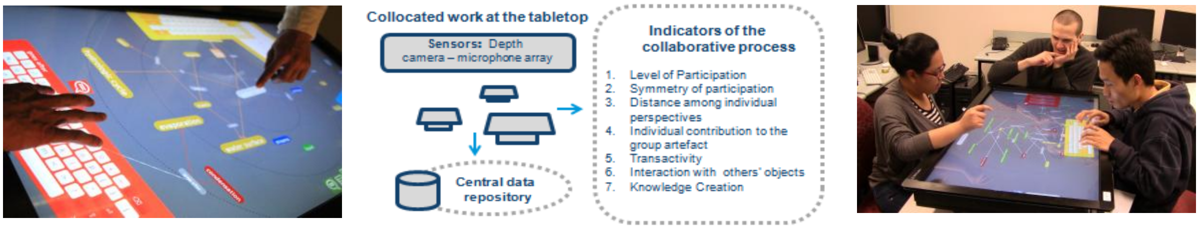

Figure 1. Learning environment being used by three learners and the variables of study.

Participants and design. Fifteen university students participated in the study. Most were enrolled in engineering courses and were aged between 20 and 26. Participants were assigned to groups of three and knew each other. The experiment had two phases: an *individual* one at a personal desktop followed by a *collaborative* one at the tabletop. The duration of the experiment included (a) a 10 minute reading phase, in which all participants read the same text about the learning domain (human nutrition and healthy diet), (b) up to 30 minutes for building the *individual* maps using the desktop application CmapTools (http://cmap.ihmc.us), and (c) up to 40 minutes for the *collaborative* phase at the tabletop (see Figure 2). For the *individual phase*, learners were requested to answer the focus question: *What types of food should we eat to have a balanced diet?* They received an initial list of suggested concepts extracted from the instructional text to start building their concept map. They were free to add their own concepts, hierarchical arrangement, and linking words.

The *collaborative phase* consisted of building a collaborative concept map at the tabletop, using an application developed by Martinez, et al. (2011a) which gives learners access to their individual concept maps and supports collaboration to create a shared concept map. Learners have access to the list of concepts they used in the individual stage. They share their concepts with others, create new concepts from scratch, and choose linking words to describe the relationship between concepts. All elements on the tabletop are coloured to distinguish which learner created which object. This phase was scripted in four stages (see Figure 2):

i) Selecting concepts; participants are asked to add the concepts that they consider are the most general from their individual concept maps. New concepts can also be added later.
ii) Adding propositions that the individual learners have in common; the tabletop accesses the individual maps, identifies similar propositions and asks learners whether they want to add these.
iii) Linking phase, in which users build relationships between concepts (propositions).
iv) Reflection on the resulting map; the application highlights potential errors (e.g. duplicate concepts) and suggests the learners consider propositions present in the individual maps but missing in the group map.

Data sources. Between 450 and 1102 meaningful *physical actions* on the interactive surface were recorded per group. Discussions were captured, distinguishing when each group member was speaking. On average, individual participants spoke between 2 and 15.6 minutes. Qualitative observations of the videos were used to assess whether most of groups' speech was on-task (an average of more than the 89% in each group). Each utterance in a sample of each session (more than the half of each session) was coded using a modified coding scheme for Collaborative Decision Making (Kennedy-Clark, et al, 2011). Off-task speech included all the utterances about anything other than the subject material, management of the group processes or the interaction with the application.

Data analysis. This study focuses on analysing a set of *variables* that measure the degree of participation, knowledge distance, and interaction within the groups (Figure 1). These variables were chosen based on previous investigations that have used them to aid empirical and quantitative studies of group learning (Dillenbourg, 1998; Molinari, et al., 2008; Paavola & Hakkarainen, 2005; Taricani & Clariana, 2006)

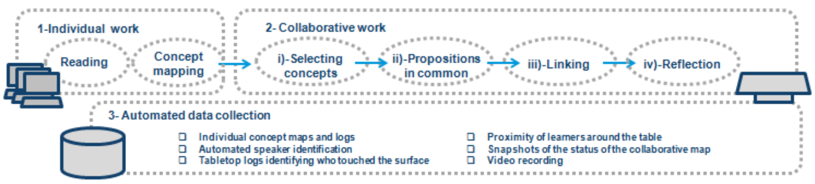

Figure 2. Approach: 1) individual work, 2) tabletop group activity, and 3) data captured automatically.

1) *Level of Participation – physical and verbal*. This dimension of the collaborative group is a very basic indicator of the extent to which one learner participates compared with other learners and groups. The first dimension of participation (physical) includes all the meaningful touches that are performed on the interactive surface (e.g. create concept, add link, and edit linking words). Verbal participation has further impact on the group decisions in face-to-face collaboration. Therefore, it was captured.
2) *Symmetry of participation – physical and verbal*. It has been found that groups in which students participate asymmetrically are frequently related to cases of free-riding or disengagement from the activity (Dillenbourg, 1998). Groups that behave collaboratively tend to allow contributions by all group members. The Gini coefficient was used as an indicator of symmetry of participation in both dimensions: physical and verbal. For this coefficient, a value of zero means total equality and a value of one indicates maximal asymmetry. Previous research on collocated collaboration in small groups found that coefficients close to .5 identify group situations that are already asymmetric (Martinez, et al., 2011c).
3) *Distance among individual perspectives*. This study aims to measure the extent to which the individual perspectives about the topic are similar to each other. This study uses concept maps as indicators of understanding. Taricani & Clariana (2006) developed a technique for scoring open-ended concept maps by comparing them with a master map. Inspired by this approach, a similar automatic technique was applied with the purpose of comparing concept maps among group members.
4) *Individual contribution to the group artefact*. Applying the same technique (Taricani & Clariana, 2006) this indicator measures the distance between the individual concept maps and the group map. This distance can be measured throughout the collaborative process to observe how individual contributions vary across time.
5) *Transactivity*. In the context of collaborative concept mapping, transactivity has been described as the extent to which a group member refers to or builds upon their peer's contribution while adding their own ideas to the group map (Molinari, et al., 2008). This indicator was measured in terms of the number of links that each learner creates using concepts that other learners had added to the group map.
6) *Interaction with others' objects*. Another way to measure interactions among a group of learners is to see how often they interact with the same objects (e.g. one learner adds a concept, then a second learner moves and edits the concept word, then a third learner creates a link using this concept). This indicates that the three learners are at least aware of the presence of the concept in the context of the activity.
7) *Knowledge Creation.* Following the metaphor of knowledge creation of Paavola & Hakkarainen (2005) this indicator measures the "created" knowledge in the context of concept mapping by distinguishing links that were used in the shared map but not in any individual map. This variable does not describe the correctness of these links; nor does it compare the map with a master map.

Results

Table 1 shows data of four trials, each with distinct behaviours for different aspects of collaborative work. It summarises the results of the variables that were measured. *Level of Participation (group)* is the number of touches or speaking time of the three participants of each group compared with the mean over all groups (312 touches per group, SD =241; 7.2 minutes of talk per group, SD=3.5). For example, the group where participants worked independently (Group 1) had 817 touches and 12 minutes of talk.

Table 1: Measures of group activity process: 1) a group in which group members worked independently; 2) a balanced group; 3) a group with a "dominant" student and 4) a group with a "free-rider".

Groups:	*1-Independent work*		*2-Balanced work*		*1- Dominant*		*4- Free-rider*	
Propositions	55		14		27		20	
	Touch	*Verbal*	*Touch*	*Verbal*	*Touch*	*Verbal*	*Touch*	*Verbal*
1-Level of participation (group)	Med 817touches	Low 12 min	Low 432touches	Med 22.6min	High 1102touches	Med 27.4 min	Med 1383touches	Med 23 min
a) Participant 1	Med-30%	Med-43%	High-45%	Med-29%	Med-23%	Low-14%	Med-37%	High-47%
b) Participant 2	Med-28%	Med-39%	Med-29%	Med-28%	Med-21%	Med-28%	High-51%	Med-37%
c) Participant 3	High-41%	Low-17%	Med-25%	High-42%	High-54%	High-56%	Low-10%	Low-15%
2-Symmetry (Gini coefficient)	0.30	0.29	0.27	0.16	0.35	0.44	0.50	0.34
3-Individual map differences								
a) P1 and P2	5%		14%		9%		21%	
b) P1 and P3	23%		8%		4%		20%	
c) P2 and P3	50%		17%		40%		35%	
4-Individual contribution								
a) Participant 1	55%		28%		30%		51%	
b) Participant 2	59%		55%		23%		53%	
c) Participant 3	54%		8%		54%		24%	
5-Transactivity (avg p/student)	1 links (SD =2)		7 links (SD =1)		10 links (SD =4)		8 links (SD =6)	
6-Interaction (avg p/student)	7 actions (SD =4)		36 actions (SD =27)		58 actions (SD =48)		28 actions (SD=22)	
7-Knowledge building (max)	45%		71%		11%		20%	

The tags *Low*, *Med* and *High* were calculated for each group (Row 1) and each student (rows 1.a, b and c) from the relative number of touches and amount of speech compared to the mean participation among groups and within each group respectively. *Low* means < mean – 1 Standard Deviation (SD), *High* > mean + 1 SD and *Med* around the mean. The indicator of *symmetry* for the physical and verbal participation was calculated using the average of the Gini coefficient sampled every two minutes. For example, the minimum Gini coefficient corresponds to the verbal participation of Group 2 (0.16) indicating that the speaking time of group members was balanced. On the other hand, a Gini coefficient of 0.5 for verbal participation of Group 4 reflects the lack of participation by one of the group members compared with the other two. Row 3 represents the distance between the individual maps of the members of the same group. P1, P2, and P3 correspond to Participants 1, 2 and 3. A score of 5% indicates that the individual concept maps shared 5% of the propositions, indicating how close their initial conceptions about the topic were before the collaborative phase. *Individual contribution* (Row 4) was measured as the *minimum* distance reached between each individual map and the final group map, or in other words, the number of propositions included in the group map from the individual maps. For example, the maximum distance was found in Group 3 between Participants 1 and 3 (4%), and the minimum distance in Group 1, where Participants 2 and 3 shared the 50% of their propositions with their group map. However, if the proposition was not added by the participant, the contribution of that specific proposition was halved. Row 5 and 6 correspond to the indicators of *transactivity and interaction* with other students' objects. Row 7 was measured as the *maximum* percentage of propositions of the group map that were not present in any individual map (e.g. a maximum created knowledge of 71% for Group 2, and a minimum of 11% for Group 3).

Analysis and discussion

This study aimed to link quantitative indicators that can be automatically captured from a face-to-face collaborative learning environment to the observed group behaviour. Results indicate that groups presented diverse quantitative indicators according to their interactions style:

Independent work / balanced work. Two groups showed opposite behaviour in terms of degree of collaboration. In Group 1, students worked mostly separately without showing awareness of others' actions. They worked independently, giving some comments to the others about their artefact but mostly being engaged in their individual work. Interestingly, the measures of symmetry indicated rather balanced group work with the participation of each group member close to the overall average (272 touches and speaking time of 4 minutes per student). However, the indicator of *transactivity* averaged just one link. This means that during the activity each student created just one link using a concept that other student added. Each student also only averaged 7 actions performed on objects created by others. As a result, they ended up building three distinct concept maps that were barely connected. Additionally, a high degree of contribution (54%) and knowledge building (45%) were observed. However, given the fact that they worked almost separately, facilitators may argue that this "created" knowledge cannot be attributed to the group work.

By contrast, the second group performed better in terms of collaboration. Table 1 shows that the participation was more balanced, especially for the verbal participation (symmetry close to 0, for touch=0.27 and speaking time=0.16). Even when their individual concept maps were not very similar (rows 3.a, b and c, <17% for the 3 students) their indicators of *transactivity* and *interaction* with elements created by others' were higher than group 1 (7 links and 36 actions per student). The level of verbal participation as a group was close to the total average across all groups. However, their effective work was relatively small (only 14 propositions in the final map). A teacher could have encouraged them to include more of their individual propositions in the shared concept map. Nevertheless, this group scored the highest rank in *knowledge creation* (0.71) because they created most propositions collaboratively.

Dominant student / Free-rider. In Group 3, Participant 3 performed most of the changes to the group map, and controlled most of the decisions (more than 600 actions while the two other students had less than 250 each) and he spoke during 16.6 minutes (around 60% of the total group speaking time). This asymmetry of participation was captured by the Gini coefficients (touch=0.35 and verbal participation=0.44). The *transactivity* and *interaction* measures were higher than in Group 2. However, these averages are skewed due to the dominance of Participant 3 who used others' concepts to create links and built the shared concept map almost by himself (Participant 3 performed 113 actions on others' elements, the others only 41 and 21 each, mean=58 actions, SD=48). As a result, the final group map showed a low score for *knowledge building* because the final solution was very close to the dominant student's map (knowledge building = 0.11 and individual contribution of Participant 3 = 54%). Another important aspect is the connection between individual map distances and the contribution to the final map. It could be expected that if two learners have similar individual maps (in this case Participants 2 and 3 shared 40% of their propositions) the contribution of both participants would be higher if one added most of his links. However, the metrics are not affected by this effect. In this case even when Participant 3 added more than 54% of their individual propositions, Participant 2 added just 23% of their map.

By contrast, the fourth group showed two learners who collaborated well to merge their ideas (Participants 1 and 2). However, the third participant did not contribute to the group effort and had significantly lower levels of participation compared with the other students (free-riding effect) contributing only to 10% and 15% of the physical and verbal participation respectively (Participant 3 had only 62 touches and 3 minutes of speech). Due to the lack of participation of this student, the symmetry of participation of the group was high (physical=0.50 and talking time=0.34). The indicators, *transactivity* and *interaction* with others' objects, were similar to all but Group 1 because the two collaborative participants worked together on the same task, building their propositions on the other's concepts and links (*transactivity* of 8 links and interaction of 28 actions per student). Participant 3 only interacted three times with others' objects and created few propositions as indicated in their low individual contribution score (24% against 51% and 53%).

Conclusions and future work

The learning process that takes place during the creation of collaborative artefacts is not normally visible in the final product. This paper presents indicators that provide summary information about the collaborative knowledge construction process that is not otherwise available to teachers from the final product. Data from case studies was automatically and unobtrusively captured from the tabletop learning environment and used to identify differences between groups. The case studies illustrate distinctive group behaviours: independent work, balanced work, a dominant student and a free-rider. Results showed the feasibility and utility of using the captured data to generate indicators that can effectively describe particular group behaviour, when compared with analysis of the video and observations. These indicators can serve as a foundation for a new form of support for teachers in classrooms where students work in small groups. Future work will focus on turning tabletop systems into adaptive learning tools that can support students. Teacher dashboards will display patterns of interactions during collaborative work using visualisation, statistical and data mining techniques. This study will extend to consider the quality of the collaboration of the group, learning gains and its implementation in school classrooms.

References

Dillenbourg, P. (1998). What do you mean by 'collaborative learning'? *Collaborative Learning: Cognitive and Computational Approaches. Advances in Learning and Instruction Series*. (pp. 1-19): Elsevier Science.

Evans, M. A., Drechsel, E., Woods, E., & Cui, G. (2010). Multi-Touch Tabletop Computing for Early Childhood Mathematics: 3D Interaction with Tangible User Interfaces. ICLS 2010. (pp. 274-275)

Kennedy-Clark, S., Thompson, K., & Richards, D. (2011). Collaborative Problem Solving Processes in a Scenario-Based Multi-User Environment. CSCL2011. (pp. 706-710)

Martinez, R., Kay, J., & Yacef, K. (2011a). Visualisations for longitudinal participation, contribution and progress of a collaborative task at the tabletop. CSCL2011. (pp. 25-32)

Martinez, R., Collins, A., Kay, J., & Yacef, K. (2011b). Who did what? who said that? Collaid: an environment for capturing traces of collaborative learning at the tabletop. *Interactive Tabletops and Surfaces*, ITS 2011, (pp. 172-181).

Martinez, R., Wallace, J., Kay, J., & Yacef, K. (2011c). Modelling and identifying collaborative situations in a collocated multi-display groupware setting. AIED 2011. (pp. 196-204)

Martinez, R., Yacef, K., Kay, J., Kharrufa, A., & Al-Qaraghuli, A. (2011d). Analysing frequent sequential patterns of collaborative learning activity around an interactive tabletop. EDM 2011. (pp. 111-120)

Medina, R., & Suthers, D. D. (2008). Bringing representational practice from log to light. ICLS 2008. (pp. 59-66)

Molinari, G., Sangin, M., Nüssli, M.-A., & Dillenbourg, P. (2008). Effects of knowledge interdependence with the partner on visual and action transactivity in collaborative concept mapping. ICLS 2008. (pp. 91-98)

Okebukola, P. A. (1992). Concept mapping with a cooperative learning flavor. *The American Biology Teacher*, 218-221.

Olson, J. S., Teasley, S., Covi, L., & Olson, G. (2002). The (currently) unique advantages of collocated work. Distributed work, 113-135.

Paavola, S., & Hakkarainen, K. (2005). The Knowledge Creation Metaphor – An Emergent Epistemological Approach to Learning. *Science Education*, 14(6), 535-557.

Rick, J., Harris, A., Marshall, P., Fleck, R., Yuill, N., & Rogers, Y. (2009). Children designing together on a multi-touch tabletop: an analysis of spatial orientation and user interactions. Paper presented at the *8th International Conference on Interaction Design and Children*, Como, Italy. (pp. 189-196)

Roth, W.-M., & Roychoudhury, A. (1993). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching*, 30(5), 503-534.

Taricani, E., & Clariana, R. (2006). A Technique for Automatically Scoring Open-Ended Concept Maps. *Educational Technology Research and Development*, 54(1), 65-82.