

An interactive teacher's dashboard for monitoring groups in a multi-tabletop learning environment

Roberto Martinez Maldonado¹, Judy Kay¹, Kalina Yacef¹, Beat Schwendimann²

¹School of Information Technologies, ²Faculty of Education and Social Work
University of Sydney, Sydney, NSW 2006, Australia
{roberto, judy, kalina}@it.usyd.edu.au,
beat.schwendimann@sydney.edu.au

Abstract. One of the main challenges for teachers in facilitating and orchestrating collaborative activities within multiple groups is that they cannot see information in real time and typically see only the final product of the groups' activity. This is a problem as it means that teachers may find it hard to be aware of the learners' collaborative processes, partial solutions and the contribution of each student. Emerging shared devices have the potential to provide new forms of support for face-to-face collaboration and also open new opportunities for capturing and analysing the collaborative process. This can enable teachers to monitor students' learning more effectively. This paper presents an interactive dashboard that summarises student data captured from a multi-tabletop learning environment and allows teachers to drill down to more specific information when required. It consists of a set of visual real-time indicators of the groups' activity and collaboration. This study evaluates how teachers used the dashboard determine when to intervene in a group. The key contributions of the paper are the implementation and evaluation of the dashboard, which shows a form of learner model from a concept mapping tabletop application designed to both support collaborative learning and capture traces of activity.

Keywords: interactive tabletop, ubiquitous learning environment, collaborative learning, group modelling, data mining, teacher's dashboard, concept mapping

1 Introduction and related work

Working effectively in collaborative settings is increasingly important both for education and work [3]. Given the importance of these skills, teachers ought to encourage enhanced performance by providing effective feedback and implementing strategies to help students to be more aware about their collaborative interactions. One of the main challenges for teachers in *orchestrating* multiple groups working face-to-face is that they need to determine the right moment to intervene and divide their time effectively among the groups[4]. Often teachers only see the final product that does not reveal the processes students followed [15]. This means teachers cannot act effectively as facilitators for the learning of group skills. This is a problem because teach-



Fig. 1 Left: Class view of the teacher's dashboard displayed in a handheld device while a group of students build a concept map. Right: The multi-tabletop learning scenario.

ers may find hard to evaluate the collaborative processes, such as the symmetry of participation [3], high quality partial solutions or students' individual contributions.

Emerging pervasive shared devices, such as interactive multi-touch tabletops, have the potential to support face-to-face collaboration by providing a shared space through which students can have access to digital content while they build a joint solution. Tabletops also open new opportunities for capturing learners' digital footprints offering teachers and researchers the possibility to inspect the collaborative process and recognise patterns of behaviour. However, teachers often do not use quantitative information about student performance to change their strategies, suggesting that teachers need real time information carefully selected and effectively presented [16].

This paper presents a teacher-driven design, implementation, and evaluation of a dashboard for guiding teachers' attention by showing summaries of real time data captured from a tabletop environment (Figure 1). Stephen Few [7] defines dashboards as "*a visual display of the most important information needed to achieve one or more objectives; consolidated on a single screen so the information can be monitored at a glance*". Our dashboard shows a set of visual indicators of collaborative activity generated by means of group models and a data mining technique exploiting tabletop data including: amount and symmetry of learners' physical and verbal activity, the progress of the group towards the goal, the interactions among learners, and domain specific indicators. The main goal is to help teachers gain awareness by visualising selected information that would otherwise remain invisible so they can determine which groups need their attention right away and whether or not to intervene.

There has been significant research exploring data captured from educational tabletops. Fleck *et al.* [8] analysed the conversations that occur among learners working at interactive tabletops and highlighted that both verbal interactions and physical touches ought to be considered to study collaboration. Martinez *et al.* [13] showed how touch data captured from these devices make it possible to analyse collaborative learning, by, for example, mining sequential patterns of interaction that are followed by high achieving groups. VisTaco [17] is a tool that visualises the low-level logged touches of users using distributed tabletops to help researchers to study group dynamics. Verbal participation around non-interactive tabletops has been modelled to create visualisations of patterns of conversation in group decision making [2]. There is also significant research on designing visual models that reveal associations between observable patterns and quality of group work. Erickson *et al.* [6] showed the benefits of

visually representing the chat conversation of a group for self-regulation. Donath [5] displayed participation in the visualisation of online group activities using a Loom visualisation. Kay *et al.* [9] created a set of visualisations to identify anomalies in online team work by mirroring aspects such as participation, interaction and leadership. The most similar research to ours was conducted by ALAgha *et al.* [1] who built a tool through which teachers can interact with groups and monitor multi-tabletop classrooms. Our work goes beyond previous work by introducing a novel approach to model and visualise aspects of collaboration unobtrusively captured from an interactive tabletop environment to support teacher guidance.

2 The tabletop-based learning environment: concept mapping

This study used an updated version of a collaborative concept mapping tabletop application [11] (Figure 2). *Concept mapping* [14] is a technique through which learners can represent their understanding about a topic in a graphical manner. A concept map includes short words that represent objects, processes or ideas (called *concepts*, e.g. protein, milk). Two concepts can be linked to create a statement (called *proposition* e.g. milk *contains* protein).

Fifteen university students participated in the case study. They were assigned to groups of three and knew each other. First, learners were asked to read the same text about the learning domain (healthy nutrition) and build their individual concept maps in private using a desktop tool (CMapTools [14]). Then, learners came to the tabletop to integrate their perspectives into a collaborative concept map (see Figure 2, right). The activity was semi-structured in four stages: i) individual concept mapping (external to the tabletop); ii) collaborative brainstorming of the concepts for the joint map; iii) adding propositions that learners had in common, and iv) the discussion phase, where learners create the rest of the propositions, by negotiating different views. They had 30 minutes for building individual maps and up to 30 minutes for the collaborative stage at the tabletop. All sessions were video recorded. At the tabletop, learners could add concepts from individual lists of concepts from the individual stage; create new links and concepts, edit propositions and have access to their individual maps.

The tabletop hardware itself cannot distinguish between users. An overhead depth sensor (www.xbox.com/kinect) was used to track the position of each user and automatically identify who did each touch. Frequency of individual verbal contributions was recorded through a microphone array (www.dev-audio.com) located above the tabletop and which distinguishes who is speaking [10].



Fig. 2 The collaborative concept mapping tabletop application. Left: Two propositions. Center: Three learners working together. Right: Integrating propositions from the individual map.

3 The interactive teacher's dashboard

It is challenging to define ways to present the information about group collaboration in a manner that is readily understood and useful for educators. For this reason we decided to include teachers experienced in classroom collaboration in early stages of the dashboard design. Features that classroom experts believed should be in a truly effective educational awareness tool included features for: identifying learners who are not contributing to the group who are dominating and controlling the activity; groups that work independently; or that do not understand the task. The dashboard was designed to enable teachers to determine whether groups or individual learners need attention, by showing the symmetry of activity, degree of interaction with others' contributions and overall progress of the task. Four teachers were involved in the *teacher-driven* design process that consisted of an iterative series of interviews, prototypes and empirical evaluations of both the visualisations and the structure of the dashboard. The final result was a dashboard with 2 levels of detail: 1) the *class level*, shows very summarised information about each of the groups so teachers can use it in real time to see several groups at once during a classroom session (Figure 1, right), and ii) the *detailed group level*, that permits in depth exploration of a specific group's activity.

3.1 The class level: accumulated summaries of each group activity

The *class level* of the dashboard aims to give minimal information needed for a teacher to gain an overview of the overall activity of each group. This layer displays sets of three visualisations per group. We now explain the design of each of these.

Mixed radar of participation. Groups in which learners participate asymmetrically are often associated to cases of free-riding or disengagement while collaborative groups tend to allow the contribution of all members [3]. This radar models the cumulated amount and symmetry of physical and verbal participation (Figure 3 - 1). The triangles (red and blue) depict the number of touches and amount of speech by each learner. Each coloured circle represents a student. The closer the corner of the triangle is to the circle, the more that student was participating. If the triangle is equilateral it means that learners participated equally.

Graph of interaction with others' objects. Studies with students working at tabletops have confirmed that interacting with what others' have done may trigger further discussion that is beneficial for collaboration [8]. This graph models the cumulated number of interactions by each learner with other students' objects at the tabletop (Figure 3-2). The size of the circles indicates the amount of physical activity (touches) by each learner. The width of the lines that link these circles represents the number of actions that the learners performed on the concepts or links created by other learners.

Indicator of detected collaboration. This visualisation shows the "level of collaboration" detected by the system as a summary of group health. It is based on a mathematical model developed by Martinez *et al.* [12] using the data mining prediction Best-First tree algorithm. It classifies each block of half a minute of activity according to a number of features that can be captured from collocated settings. They are: num-

ber of active participants in verbal discussions, amount of speech, number of touches and symmetry of activity measured with an indicator of dispersion (Gini coefficient). The system labels each 30 second episode as one of three possible values: Collaborative, Non-collaborative, or Average. The visualisation shows the accumulation of these labelled episodes. The arrow bends to the right if there are more “collaborative” episodes or to the left if there are more “non collaborative” episodes (see Figure 3-3).

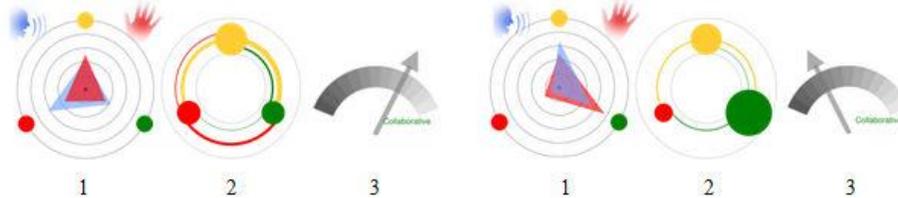


Fig. 3 Overview visualisations. Left: a balanced group (Group A). Right: a group in which one member (red circles) was completely disengaged from the activity (Group D).

3.2 The detailed group level: detailed timeline summaries for a specific group.

The group level visually depicts information over time for *post-mortem* analysis. This level is accessed by touching the set of visualisations of a specific group in the *class level*. It includes the next five visualisation types.

Evolution of the group map. This visualisation shows the contributions of group members towards the group map, by displaying the number of propositions (links) created and their authors, along the time line (Figure 4). The small coloured circles indicate a “create link” event generated by the learner identified by that colour. In this way a teacher can become aware of dominant participants, see patterns of alternating contributions or whether all members contribute to the concept map evenly. The red flags (C, L) indicate the stages that students explicitly started: The first stage is brainstorming starting from minute 0 (not flagged). C= adding propositions learners have in *Common*, L= *Main Linking* phase. This is the only visualisation of the dashboard that is coupled with the concept mapping task.

Timeline of interaction with other learners’ objects. This visualisation depicts the amount of interaction by each learner with others’ objects. Each coloured horizontal line represents a learners’ timeline. Each vertical line represents an interaction of that learner with other learners’ objects. Figure 5 (left) shows the interactions of a group in which one learner (Alice, red coloured) dominated the physical interactions with her peers (Bob and Carl, green and yellow). Figure 5 (right) shows a group where learners hardly built upon other’s ideas, as there are very few interactions.

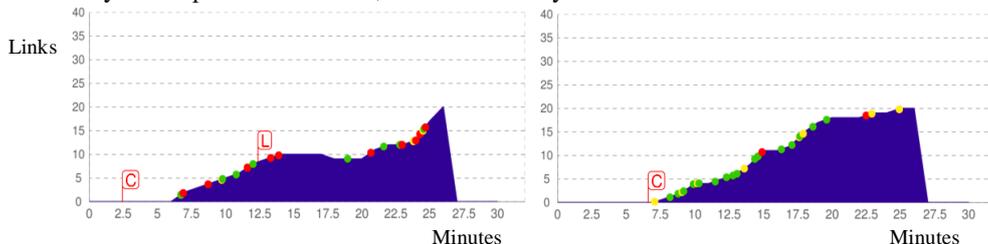


Fig. 4 Evolution of the group map. Left: A group with a dominant student (red) and a low participant student (yellow) (Group C). Right: A group with a low participant (red) (Group D).

Radars of verbal and physical participation in the timeline. These visualisations model the amount and symmetry of verbal (Row 1, Figure 6) and physical participation (Row 2, Figure 6) of each group member. Similarly to the cumulative radars described in the previous section, if the corner of the triangle is closer to the centre (black dot), that means the corresponding learner's activity was low.

Contribution charts. These visualisations model the dimension of the concept map in the tabletop in terms of propositions. They also show the distribution of the individual contribution to the group concept map. The size of the charts indicates the number of links in the concept map. In the dashboard, these visualisations cover 4-5 minutes of activity. Therefore multiple visualisations are shown in the timeline (Row 3, Figure 6).

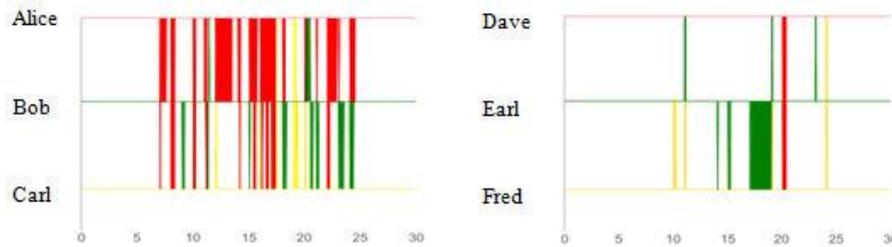


Fig. 5 Timeline of interaction with other learners' objects. Left: A group with a dominant learner (Group C). Right: group members that worked independently (Group B).

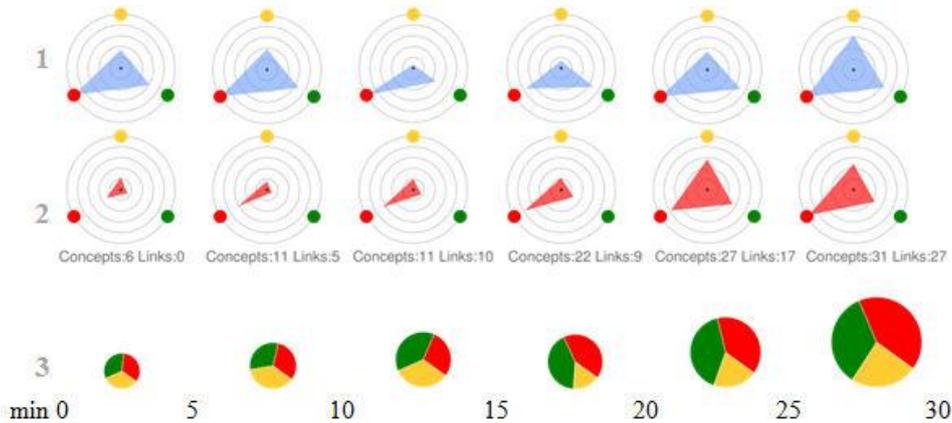


Fig. 6 Radars of verbal participation (Row 1), radars of physical participation (Row 2) and Contribution charts (Row 3) of a group with a dominant student-red coloured (Group C).

4 Evaluation

We aimed to evaluate two research questions: (Q1) *Is the class level of the dashboard useful for teachers to decide when to intervene or which groups need their attention?*

(Q2) Which visualisations (in both levels) do teachers use to decide whether groups need attention?

Eight teachers experienced in small-group classroom collaboration participated in the evaluation sessions. None had been involved in the design of the dashboard. The data recorded from four groups, each with three students, was used. Groups were cross-distributed among teachers so that each teacher monitored three groups at the same time and each group was monitored by six teachers. The system simulated the real time generation of data for the teacher, as if he or she was monitoring three groups during 30 minutes. This version of the dashboard presents up to three groups at the same time. In parallel, each group video was manually analysed by an external person to diagnose groups' collaboration and have a baseline reference of group performance. Based on these observations, groups can be described as follows: Group A performed best in terms of collaboration. Students discussed their ideas, worked together to build the group concept map. They completed the task sooner than the other groups and their final solution was simpler. By contrast, members of Group B worked independently most of the time, building three different concept maps rather than combining perspectives into a shared map. Group C was distinguished by the dominance of a single student, who led the discussion, took most of the decisions and ended up building most of the group map without considering others' perspectives. In Group D, only two learners collaborated to merge their ideas. The third learner did not contribute to the group effort and had lower levels of participation – *free-riding*.

The evaluation recreated the classroom orchestration loop documented by Dillenbourg *et. al.* [4]: teachers monitor the classroom, compare it to some desirable state, and intervene to mentor students. This was adopted as follows: (1) First, teachers were asked to think aloud as they were looking at the *class level* of the dashboard, verbalising their perception of each visualisation. (2) Then, they were asked to state whether each group was collaborating. (3) As appropriate, they would select the visualisations that indicated that a group might have *anomalies* in terms of collaboration. (4) As appropriate, they would choose one group (or none) that they would attend to, indicating which visualisations helped them to take such decision. (5) As a response, the system drills down from the *class level* to the selected *detailed group level* of the dashboard. (6) Then, teachers were requested to think aloud, stating the visualisations that helped them to confirm possible *anomalies* and whether they would talk with the group members or provide corrective feedback. If the teacher decided to intervene they had to wait at least 2 minutes in this layer without viewing other groups (simulating the time taken to talk with the group). Teachers followed this loop throughout the 30 minutes duration of the trials. Finally, they were asked to answer a short questionnaire to validate that they understood the visualisations. Data captured from the teacher dashboard usage sessions were recorded and analysed.

5 Results and discussion

(Q1) Is the class level of the dashboard useful for teachers to decide when to intervene or which groups need their attention? This research question drove the study.

Our objective is to help teachers recognise potential issues within the groups so they can be more aware about which group needs attention. Table 1 shows the two main evaluation aspects: which group teachers would visit next and why (*attention*), and if they would either intervene or let the group continue working (*intervention*). During the experiment *attention* was indicated when teachers navigated from the *class level* to the *detailed group level* of the dashboard. *Interventions* were indicated when, after analysing the group level of the dashboard, teachers felt that the group still needed to take corrective actions to improve collaboration.

Results indicated that teachers would focus most of their attention on groups B and D (investing 44% and 40% of their time on average in them). They correctly identified independent work and the presence of a free-rider as their major issues. They indicated interventions would had served to encourage students to work more collaboratively and share their ideas with others (on average 4 interventions out of 7 moments of attention and 3 interventions out of 6 moments of attention respectively per teacher). Group B claimed a similar degree of attention (13% of intervention out of the 31% of attention per tutor). In fact, the difference in the *attention* across these three groups was not significant ($p>0.05$). However, for all of the tutors, Group A was clearly performing well and teachers would not have intervened (average of 2 visits and 0.7 interventions per tutor). The attention provided to other groups compared with Group A was statistically significant ($p<.00027$, two-tailed). Inter-tutor agreement was calculated to examine how different the observations. Table 1, Column k (Cohen's kappa) shows that the 6 tutors who monitored each group agreed on *which* group needed intervention and *when* they needed it either at the beginning, in the middle or by the end of the task- $k > 0.4$.

Group	Attention		Interventions		K	Observations based on the videos
	Att	Att%	Int	Int%		
A	2 (s=1)	15% (s=7)	1 (s=0.5)	4% (s=3.4)	0.7	Even group
B	7 (s=2)	44% (s=7)	4 (s=1.4)	21% (s=6)	0.4	Independent work
C	5 (s=1)	31% (s=6)	2 (s=0.6)	13% (s=3)	0.5	Dominant student
D	6 (s=3)	40% (s=13)	3 (s=1.7)	19% (s=8)	0.5	Free-rider

Table 1. Teachers attention and interventions per group. Att= Average number of times each tutor decided to monitor that group. Att%=Average proportion of moments dedicated to that group. Int=Average number of interventions. Int%=Average proportion of interventions. k= Inter tutor agreement (Cohen's kappa).

(Q2) *Which visualisations (at both levels) do teachers use to decide whether groups need attention?* Based on the think aloud analysis of the *class level* visualisations, we found that teachers agreed on the usefulness of the *mixed radar of participation* and the *chart of interactions with others' objects* graphs. These provided them with enough information to identify possible problems within certain groups. Some tutors indicated that the third graph, *indicator of detected collaboration*, was useful only to *confirm* their observations using the first two charts. Table 2 shows that teachers obtained more information from the two first visualisations (85 and 65 detected issues) and started to use them from the beginning of the activity. They identified the main anomalies of groups B, C and D describing the main problems with the groups:

independent work and a low participant for Group B, a dominant student in Group C and a free-rider in Group D. They were not concerned about Group A (Table 1, 15% for *Attention*). Four out of 6 tutors indicated that Group A progressed quickly and finished the activity quickly, so in a real scenario they would have encouraged them to explore more ideas to complete their work. Teachers indicated that the detailed timeline level of the dashboard provided information about the *progress* of each group. All agreed that this level would become an important tool for after-class analysis but the *class level* of the dashboard provides enough information to identify possible anomalies during a classroom session. Table 2 shows that tutors tended to use all the *timeline* visualisations in combination to detect *issues* (usage between 22 and 36). However, it does not provide useful information during the first 10 minutes of the activity while the *class level* provides rich information from beginning to end of the activity (Table 2, column Min 10). Our analysis indicates that teachers could identify the major groups anomalies based on the *class level* and confirm them after looking at the *detailed group level*. Visualisations were understood by teachers (96% of correct answers in post-study questionnaires) and helped them divide their attention effectively according to groups' needs. Quantitative data does not provide details of group's collaboration but it provided information for teachers to infer whether groups were potentially engaged in non-collaborative activity.

Visualisation	Total	Min 10	Min 20	Min 30
Level 1 – Class				
Mixed radar of participation (audio and touches)	85	36	23	26
Chart of interactions with others' objects	65	18	29	18
Indicator of detected collaboration	26	8	6	12
Level 2 – Detailed group				
Evolution of the group map	22	1	8	13
Timeline of interactions with other's objects	35	3	18	14
Radars of verbal participation in the timeline	31	8	13	10
Radars of physical participation in the timeline	36	7	15	14
Contribution charts	26	7	7	12

Table 2. Potential group anomalies identified by teachers using each visualisation.

6 Conclusions and further work

The goal of this research is to present real time data from interactive tabletops, combined with data mining results, in an interactive dashboard that helps teachers monitor group activities at a multi-tabletop learning environment. We present the design and evaluation of the teacher dashboard that shows information at two levels: a class summary and a detailed group timeline. Evaluation results indicate that the dashboard allowed teachers to effectively detect which groups encountered problems in terms of collaboration. The *class level* of the dashboard provided information from the beginning of the activity and was used as a decision making tool to help teachers manage

their attention and interventions. The *detailed group level* shows chronological information that was considered effective for assessing task progress after class. Our evaluation is limited to pre-recorded data for the purpose of repeatability. Most of the visualisations contained in the dashboard can be generalised to other domains. A follow-up study can include a real study that analyses reactions from students to teacher's interventions. Future research will evaluate this tool in a real classroom and explore ways to integrate the dashboard into teachers' strategies and experience.

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