Orchestrating a Multi-tabletop Classroom: From Activity Design to Enactment and Reflection

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ABSTRACT
If multi-tabletop classrooms were available in each school, how would teachers plan and enact their activities to enhance learning and collaboration? How can they evaluate how the activities actually went compared with the plan? Teachers' effectiveness in orchestrating the classroom has a direct impact on students learning. Interactive tabletops offer the potential to support teachers by enhancing their awareness and classroom control. This paper describes our mechanisms to help a teacher orchestrate a classroom activity using multiple interactive tabletops. We analyse automatically captured interaction data to assess whether the *activity design,* as intended by the teacher, was actually followed during its *enactment*. We report on an authentic classroom study embedded in the curricula of an undergraduate Management unit. This involved 236 students across 14 sessions. The main contribution of the paper is an approach for designing a multi-tabletop classroom that can help teachers plan their learning activities; and provide data for assessment and *reflection* on the enactment of a series of classroom sessions.

Author keywords: User-centred design; Collaborative learning; Interactive Tabletops; Classroom Orchestration

ACM Classification: H5.2 Information interfaces and presentation: User interfaces, Input devices and strategies.

INTRODUCTION
Collaboration has proved successful in helping groups to achieve improved critical thinking and higher levels of thought that can lead to more effective learning outcomes [4]. This motivates teachers to use small group activities in their classrooms. However, group work also poses its own challenges, particularly in terms of the teacher's ability to support each group effectively. These include time constraints; class control skills; a different learning pace of each group; and limitations imposed by the activity [6].

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Interactive tabletops have significant potential to support a number of different aspects of education, spanning from providing a shared and enriched interactive space which can promote students collaboration [14, 20, 26, 27], to supporting teachers by improving their awareness [17, 18] or their control over a class [1, 10, 19]. Nonetheless, Muller-Tomfelde and Fjeld [21] warned about the initial overstated enthusiasm triggered by the novelty of interactive surface technologies that has not been followed by a broad adoption of such devices for real-world applications. Similarly, tabletops also offer diverse forms of educational promise [11]. However, there are still unanswered questions about the ways teachers can best take advantage of their affordances [5]. Research needs to be done to help teachers shape these technologies to match the learning objectives.

This paper describes an approach to exploit the affordances of interactive tabletops to provide a teacher the tools to monitor a classroom activity; *orchestrate* the whole class of students working in small groups; and reflect on the sessions for a possible re-design. The metaphoric term *classroom orchestration* is used to describe the role that teachers take as managers and coordinators of the cognitive, pedagogic and technological resources in the classroom, to help students achieve the intended goals of the learning activities [6, 24]. The effectiveness of orchestration and the extent to which teachers can respond to the ways students perform the class tasks is critical because it directly impacts these students' activities, and therefore, their learning [6]. The use of technology-based tools in the classroom can improve the teachers' management of the class and enhance their awareness of learners' activity. However, this requires the involvement of teachers' classroom practices in the design of the activities [2].

We report the key elements of an approach to help teachers to monitor and reflect on their classroom activity design making use of multi-touch tabletops. A series of 14 sessions of the same 1-hour tutorial were organised by a teacher to *enact* this design. These tutorials covered a topic in the formally defined set curriculum of an undergraduate-level subject. We explored the affordances of interactive tabletops to support the tutorial learning goals and to examine the consistency between the design intentions (specified by the teacher) and what actually occurred in each of the 14 classes. We evaluated our approach on three levels: assessment of how closely the class *script* was followed, measurement of *equality* of students' participation within each group, and evaluation of the achievement on the *learning outcomes*. The main contribution of the paper is an approach for designing multi-tabletop classroom systems that can help teachers to *plan* and *orchestrate* their classroom activities; and data to *assess* and *reflect* on the enactment of a series of classroom sessions. A secondary aim of this paper is to present our system, with its minimalist orchestration tools and interaction data capture functionalities, that enables a teacher to control and monitor a multi-tabletop classroom.

RELATED WORK

Several research projects have explored the use of interactive tabletops in learning contexts [13, 20, 25-27], but that previous work has been mostly limited to cases where students interact on a single table in a *controlled* learning environment, rather than on multiple tables in classroom scenarios [19]. Our work draws on some of these studies including the work done by Stock et al. [27] that explored the affordances of tabletops to help students discuss a challenging topic. We also build on the work by Kharrufa et al. [13], who described an approach for designing tabletop applications based on theories of scripted collaborative learning. Fleck et al. [8] also highlighted the importance of analysing both the verbal communication and students' physical actions with the shared device. Similarly, Rick et al's OurSpace [25] was used to investigate indicators of collaboration that could potentially be automatically measured from students interactions. Moreover, Schneider et al. [26] suggested that learning tabletop applications should provide support for reflection, engagement, and provision of feedback. Morris et al. [20] investigated the importance for groups to receive feedback at the tabletop with or without the presence of an instructor.

However, there are some important recent projects studying the role of multiple tabletops in classroom scenarios. One of the most relevant projects on multi-tabletop environments is SynergyNet [1]. This is a classroom with four multi-touch tabletops that has been used to run experiments with elementary school students engaged in an extracurricular problem solving activity (called Mysteries). This system permits the teacher to remotely control the classroom through a teacher's tabletop console. The teacher can visualise, interact with and control each group's tabletop screen from the console. The work involved qualitative observations of video-recordings to study how tabletops can support their collaborative learning interactions and the ways the teacher uses the system [19]. However, the task that students were asked to complete was outside their normal subjects and the teacher was not involved in the design of the class activity. Another reasonably similar learning environment was presented by Do-Lenh [7]. This consists of four non-multi-touch tangible tables that can keep track of fiducial markers attached to objects located on a flat surface. The learning activity was based on a simulation training application for logistics. The author presented a couple of tools to help a teacher orchestrate the classroom. These were a wall display that shows task progress and controls for the teacher to compare two groups' answers; and paper cards that a teacher could use to control individual tables. However, this work mostly focused on evaluating the *usability* of their tools on a specific case rather than integrating the teacher in the activity design or linking the task to the regular curricula. Martinez-Maldonado et al. [18] presented a dashboard that helps teachers monitoring up to three groups working at multi-touch tabletops. This dashboard showed live indicators about symmetry of verbal participation, amount of touches, progress on the task and interaction with others' objects. This project used real data from individual groups, but the evaluations were based on *simulated* concurrency.

In summary, these three previous approaches provided excellent background studies, but were not deployed in an authentic setting. This means that even when real students or teachers were involved in the studies, the tasks were not designed by the teacher and all sessions were experimental and not linked with authentic curricular activities. None of them addresses our key concerns of supporting a teacher in designing, orchestrating and reflecting on the design of an authentic activity as part of the curriculum. There was also limited automatic data capture. The information captured has mostly been targeted to researchers, designers or for in-class use only. Our work goes beyond these previous works by providing an approach to help teachers evaluate their classroom activities *design* in authentic tutorials using multiple interactive tabletops and orchestration tools. We also show that it is possible to pervasively capture rich classroom and students' data through the interactive tabletops. Then, these data can enhance the teacher's post-class *reflection* and *assessment* on the activity design and how it played out over delivered sessions.

SYSTEM OVERVIEW

We created a multi-tabletop classroom system using the following design guidelines, based on our critical analysis of previous work on classroom orchestration [6, 7], multi-tabletop classrooms [1, 18], and the specific requirements posed from the teacher in our study.

Teacher classroom control. All tabletops should be controlled by the teacher; this control should be simple and effective [6]. In particular it should be minimalist, so as not to add cognitive load to the teacher. It must be well integrated in the classroom, so the teacher does not get distracted from their teaching tasks.

User-friendly student user interface. The students' interface should be simple so that students can learn to use it within a few minutes, even on first use. This avoids wasting classroom time, considering a class session lasts only 50 minutes in our case.

Student action differentiation. It is important to distinguish which student performed each touch. This is needed to automatically identify each student's contributions or group dynamics such as dominance, leadership or disengagement.

Classroom activity capture and gathering. Distinguishing users and keeping track of all learners' actions is essential for creating monitoring tools that present overviews of students' actions or assess the match between the designed and actual enacted activities [15]. These monitoring tools should be able to access the captured information in real time and also make it available to the teacher for further activity re-design.

Hardware

Based on these guidelines, we designed our multi-tabletop classroom. The classroom has a non interactive wall display connected to a teacher's laptop (Figure 1, a, shows the projector for this). Four multi-touch tabletops were placed in the room. These are composed of 46'' PQ Labs Multi-Touch overlays[1], placed over digital screens of the same size, which can detect up to 32 touches simultaneously (Figure 1, d). The hardware itself cannot distinguish the user who touches the screen. To obtain this information, we used a depth and vision-based system to distinguish each user's touches. This system tracks users' hands through overhead depth sensors[2] that are located on top of each tabletop (Figure 1, b). This touch identification system proved to be adequate in general terms with respect to the real world needs of this setting where students tended to stay seated at the same positions around the tabletops, as compared to the controlled environment studied in [15]. A directional microphone array was placed at the centre of the four tabletops to detect levels of sound that each group produced (Figure 1, c).

Software

We created a set of interconnected software that makes the classroom work as a single piece of technology, orchestrated by the teacher. Our two main applications, visible to the users, are: the teacher's orchestration tool and the learning application displayed in each tabletop.

Teacher's orchestration tool. The tabletops are controlled by the teacher through the *orchestration tool*. This is a multi-platform application that can be displayed on devices, such as a handheld, a desktop computer or at another tabletop. For the sessions described in this paper, it was displayed on the teachers' laptop computer. We used a participatory design process with iterative prototyping, with the teacher driving and responding to designs. This process

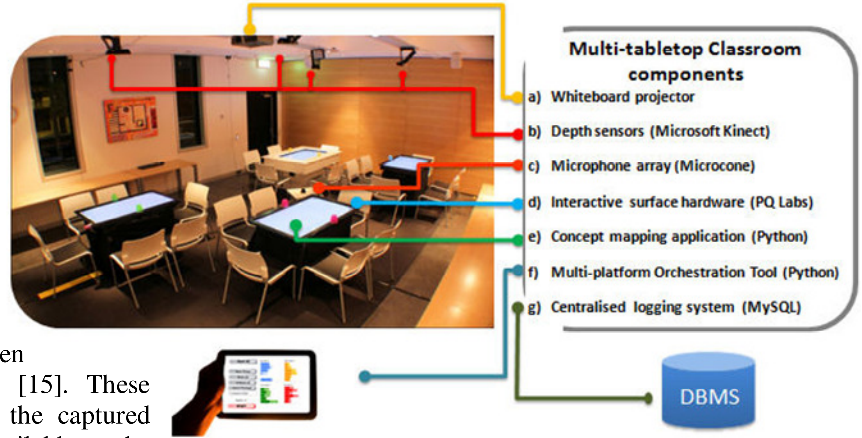

Figure 1. Multi-tabletop classroom components

identified five actions. The functions available are shown in Figure 2. The first is a synchronous *start* command that orders all the tabletops to start the activity. The second makes the tabletops *move from one phase to the next one* if the activity is divided in phases. Another functionality is the *freeze* feature, which blocks all tabletops in cases when teacher wants the attention of the class, and does not want students distracted by using the tabletop. The *broadcast a message* option can be used to, for example, send a time limit reminder that appears in front of each student. Finally, for the end of a class, the teacher can use the *reset* option to clear all tabletops and get them ready for the next class (with different students). Teachers can configure the dashboard to display a visualisation of each group's activity, as shown at the right of Figure 2. It shows a simple two-part bar that summarises the level of participation of each student in the activity, which was divided into two phases. It was designed to help the teacher identify individuals who may have low level of participation.

Learning application. Four interconnected instances of a minimal version of a *collaborative concept mapping application* [16] are loaded onto each tabletop (Figure 3). Concept mapping has proved effective in enhancing meaningful learning [22]. Through creating concept maps, students externalise their understanding by identifying relevant *concepts* and relationships between them, using *linking words* to create *propositions or links.* These can be read as statements. In the domain of Management, some examples of propositions are: "HR Director – reports to - CEO" or "HR Director –fires 25 of the- Low level staff".

Figure 2. Teacher's orchestration tool.

[1] PQ-labs, Multi-touch http://multi-touch-screen.com/

[2] Microsoft Kinect. http://www.kinectforwindows.org/

Users can create a complete concept map about a topic in minutes by performing three possible actions: 1) *adding a concept,* by selecting it from an initial list of key concepts provided by the teacher (Figure 3, A); 2) *creating a linking word* that joins two different concepts, by dragging and dropping one concept onto the other, and then selecting a word from a list of suggested links provided by the teacher (Figure 3, B); or 3) *editing a concept/linking word,* that is fired when a student dwells on any concept or link. This brings up a virtual keyboard in front of the user who performed the selection (as resolved by the depth camera). Students can also perform other intuitive actions such as moving, deleting and resizing elements to create a concept map similar to the one shown in Figure 3, D. All captured applications logs are recorded on a central common repository (Figure 1, g).

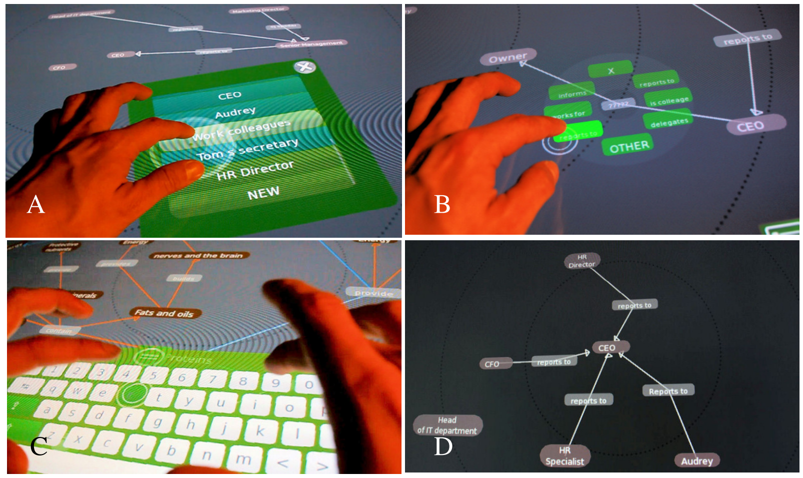

Figure 3. Minimal application for concept mapping

SMALL-GROUP CLASSROOM ACTIVITY

A learning activity was designed to fit into tutorial sessions with undergraduates in the unit: *Foundations of Management* taught in the School of Business at the *University of Sydney.* This has weekly fifty minutes tutorials that involve discussion of a previously defined case-study. Tutorials are often run as a teacher-led class discussion or by organising students in small groups. The teacher decided to use interactive tabletops to support these small group discussion activities for all the tutorials in Week 9. Importantly, the class design involved collaboration between the teacher and tabletop team to ensure that the design of the classroom activities was carefully crafted to make effective use of the multi-tabletops. Next, we describe the phases of the learning activity in terms of the timing, tools, tasks and learning objectives as intended for each repeated tutorial. Figure 4 shows the formalisation of the design using a representation developed by Prieto et al. [23]. This very concise form is gaining increased use by researchers to document orchestration plans. In this diagram we observe teacher and students actions that occur at different social levels (*classroom and small groups).* We explain each part of it in the next sub-section with special emphasis on the various *tools* available and the *atomic actions* performed by the teacher during the enactment.

Activity Design

1-Objectives explanation (10 minutes). First, the teacher explains the structure and goals of the tutorial (1a in Figure 4). Here, the objective of the tutorial is to solve a problematic scenario within an organisation. This is described in two pages provided to students one week earlier, and which they have to read as preparation. Then, the teacher explains the main concepts of the topic, and how to use the tabletop application to build a concept map (1b). The teacher makes sure that everybody understands this by walking around and stopping to check each table.

2- Activity 1 at the tabletop (15 minutes). For this activity, students are asked to *create a concept map that represents the case study organisational hierarchy and the stakeholders' power level.* This first concept mapping task enables students to establish shared understanding of their approaches to the problem, based on their preparatory reading and thinking. The tabletop application provides students with a list of the main concepts extracted from the

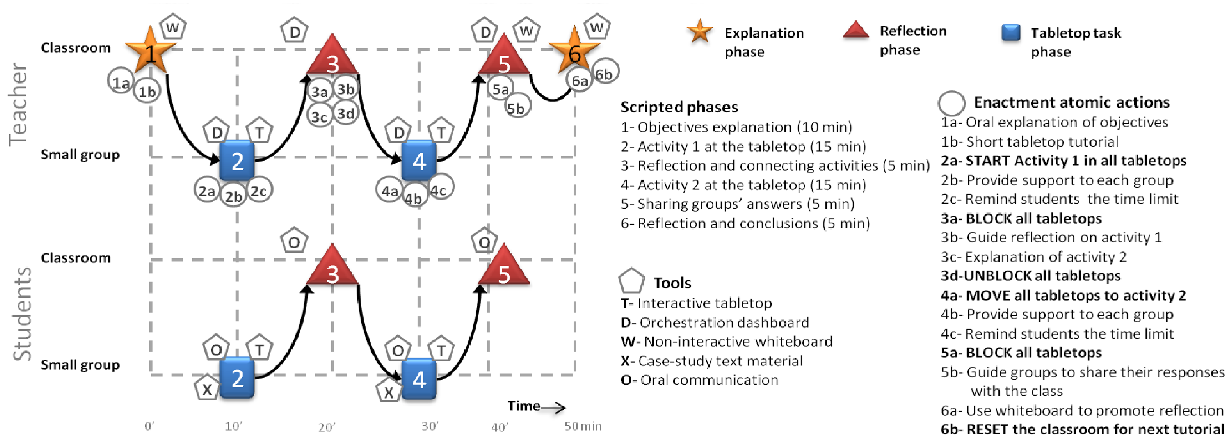

Figure 4. Design plan for the activity using the multi-tabletop classroom. This is scripted in 6 phases. Two are performed at the interactive tabletops (blue squares). The actors are students in small groups (lower), and their teacher (upper). The right half shows the phases, tools and atomic actions.

text material by the teacher. These correspond to different role players within the organisation (e.g. CEO, HR Director, Low level staff). Students can also create their own new concepts. The provision of starting concepts is important for ensuring the class to focus on the creation of the relevant propositions in the limited time available.The final product should contain the key concepts of the problem, their relationships and reflect the distribution of power within the organisation. The teacher starts the activity (2a), walks around reviewing progress and joins the discussion of some groups (2b). The teacher makes sure students are always updated on how much time they have left, by verbally reminding the class or by sending a message to all tabletops through the orchestration tool (2c).

3-Reflection and connecting activities (5 minutes). After about 15 minutes from the start of *Activity 1* the teacher stops students' activities by blocking all tabletops (3a), leads the reflection on *Activity 1* (3b), and then describes *Activity 2* (3c) explaining how it builds on *Activity 1*. When finished, the teacher unblocks all tabletops (3d).

4- Activity 2 at the tabletop (15 minutes). To start Activity 2, the teacher uses the orchestration tool to send a command to all tabletops (4a). *Activity 2* called on students to *provide a new piece of information about the problem by modifying the concept map built in the Activity 1. S*tudents are provided with additional concepts and different linking words to use in new types of propositions. The teacher moves around the class, meeting each group (4b). The teacher can send a time limit reminder through the orchestration tool (4c).

5- Sharing groups' answers (5 minutes). After about 15 minutes of the *Activity 2,* the teacher stops students by *freezing* all tabletops (5a). The teacher asks each group to share their solutions with the rest of the class (5b).

6- Reflection and conclusions (5 minutes). The teacher uses the notes on the whiteboard to summarise the key ideas students should take away from the tutorial and also to link it to the theories on this topic (6a). Then, the teacher resets all tabletops using the orchestration tool, ready for the next class (6b) that sometimes starts in the next 5 minutes.

Next, we describe an evaluation that highlights the affordances of our system for monitoring the match between, teacher's intentions as captured in the design shown in Figure 4 as well as those in the second column of Table 1, and the enactment of the 14 tutorials.

PRACTICAL EVALUATION: *from design to enactment*

We aimed to enable the teacher to evaluate how well the actual class matched the design intentions, particularly those that were specifically designed to exploit the tabletops affordances. Our approach did not simply adapt the pre-existing learning activities to an interactive surface: this may not translate into an improved experience and can lead to force activities that may not be ideal for these devices

Figure 5. Multi-tabletop classroom enactment

[3]. Interactive tabletops offer new opportunities for helping students and people to collaborate [13] but they also introduce new challenges. If well exploited, the affordances can create opportunities to foster collaborative learning. One key part of the appeal for a teacher to undertake this project was the opportunity to evaluate and reflect on the way the design played out in the real classroom.

The tutorials unit had 236 students scheduled in 14 tutorial slots. In each tutorial session small groups were formed to give diversity in terms of gender and international versus domestic students at each table. Students knew their peers well as they had met over several weeks before. In each tutorial session, there were at least three students per table and a maximum of six. Data from sessions was captured, including: application logs with user information, snapshots of the evolution of each group's concept map solution, and the actions performed by the teacher on the orchestration tool. Figure 5 shows one of the sessions. During classes, the teacher freely moved among the tabletops, reviewing each groups' concept map and identifying groups that needed help. The teacher had access to the orchestration tool through a personal computer. Three semi-structured interviews were held with the teacher after the tutorials to investigate the teacher's observations of the enactment. One of these included the presentation of the results described in the next section to collect the teacher's reflections and considerations for future re-design. Additionally, we used participant's data, as well as observations, in order to capture teachers' intentions, actions and reflections.

Table 1 shows the teacher's design intentions (Column 2) and the data that our system captured during the enacted tutorials to assess how well these intentions were met (Columns 3, 4). These were grouped into three categories: *collaboration* and *equality* of student participation (A), the adherence to the class *script* over all the sessions (B), and the achievement of the *learning outcomes* (C). The first two aspects apply to other contexts. The *learning outcomes* are connected to the particular activity of this study.

Collaboration and equality. Multi-touch tabletops offer equal opportunity for each user to provide input. One of the priorities for the teacher was to encourage and foster groups' collaboration. The intention of the teacher was that all groups could engage in productive discussions with all the students involved in the co-construction of the solution. The capture of this dimension of collaboration is beyond the scope of our system (Table 1, Rows A3, A4). Another more modest attribute of collaboration, that has proven to be important for teachers to be aware of, is the amount of participation of each student in their group activity [12]. For this, our system can automatically capture and analyse the balance of the physical participation (touches) and the contributions of each group member to the shared product (i.e. to the group map) (Table 1, Rows A1, A2). We used application logs and the analysis of group products to determine the equality within each group.

Adherence to the class script. The second set of teacher's intentions was associated with the effectiveness of the teacher to stay on track, following the planned sequence of activities (Figure 4) and the time limit for each task. One possibility is that the time planned for a certain activity is actually an over or under estimate, so requiring a change in the design. It could also be the case that the teacher inadvertently modifies the way the script is followed for some sessions, therefore, impacting on students' learning goals. Interactive tabletops and the orchestration tools can improve awareness of the process the teacher actually followed in the classroom. We investigated three design intentions set by the teacher. The first two relate to the time the teacher spends orchestrating each activity (Rows B1, B2). The third design intention is about the student response to the time allowed for each activity (Row B3). The logs of the orchestration tool indicate the teacher's behaviour and the tabletop application logs show students' task progress.

Learning outcomes of activities 1 and 2. Two learning goals were set for the tutorials. The aim for the first activity was two-folded: students should identify the key concepts of the case problem and visually represent the relationships between them (C1) and the distribution of power within the example organisation (C2). The tabletop application can validate the concepts and the propositions contained in each group map by comparing them with a *master map*. This contains the key concepts, linkages and hierarchical layout that the teacher expected from students' maps. For *Activity 2,* the learning goal was to discuss about possible solutions to the case and justify why they chose a final solution for the situation within the example organisation by augmenting the concept map produced in *Activity 1* (C3).

RESULTS: *...and reflection*

We now report results of the evaluation of the teacher's design intentions based on data from the 196 students, who agreed to make their interaction data available. They were organised in 40 groups: 10 had six students, 17 had five, 12 had four and 1 had three. Data from interviews with the teacher, as well as from non-participant observations were used to triangulate evidence.

Collaboration and equality

Each member should participate equally (A1). We assessed whether groups' physical participation and contribution were balanced within each group. In practice, it is hard for groups to achieve exact balance. Groups may be influenced by a number of factors and the individual style of group members. One indicator of group symmetry in tabletops is the *Gini index* [9]. This is a measure of dispersion that represents the inequality among values in a frequency distribution with a single number between 0 and 1, where 0 is perfect symmetry and 1 total inequality. Figure 6 shows the extent to which physical participation (meaningful touches on the surface) and contribution (parts of the final product added by each student) were equally distributed among group members. On *equality of participation* in *Activity 1* (A1), more than half of the groups (26 groups out of 40) had high levels of equality (Gini index <=0.4). But in *Activity 2* this equality dropped to only 15 out of 40 groups. This difference was statistically significant ($t(47) = 2.71$, $p < .0094$) indicating physical activity on the table was more egalitarian in *Activity 1* than in *Activity 2*. After looking at these results, the teacher commented that in Activity 1

	Teacher's design intention	Data collected during the enactment	A
	Collaboration and equality (general)		
A1	Each member should participate equally to some extent	Equality in participation from application logs	YES
A2	Each member should contribute equally to the group solution	Equality in contribution from the final maps in activities 1 and 2	YES
A3	All groups should participate in in-depth group discussions	-	NO
A4	All groups should demonstrate collaboration between team members	-	NO
	Adherence to the class script (general)		
B1	Each class activity at the tabletop should take the planned amount of time	Orchestration logs show the duration of the activities and the impact on groups' performance	YES
B2	The explanation and reflection phases should keep to the time	Orchestration logs show the duration of the phases and the impact on the duration of the activities	YES
B3	All groups should start discussing and visually representing their ideas as soon as the tabletop activities start	Application logs show the time and evolution of the physical construction of groups' products	YES
	Learning outcomes activity 1 (concept mapping)		
C1	All groups should identify the key concepts of the topic and their relationships, and avoid irrelevant concepts.	Application logs show the key concepts and relationships created by each group	YES
C2	All groups should understand the power distribution of the key concepts/players of the case	Final products logs indicates the physical arrangement of objects in the tabletop surface indicating power distribution	YES
C3	All groups should have discussions of different possible solutions and be able to justify their solution	-	NO

Table1. Teachers' intentions and data that captured from our system (A=Is it possible to assess it from the captured data?).

"*everyone starts with the same basis so at the beginning they don't know who's the leader, who understood the case … I am not surprised that groups tended to be equal in activity one*". This difference can also be explained by the nature of *Activity 1*. This consisted of building the organisational structure, working in a group, and drawing on each individual's preparation for the class. For *Activity 2,* it was observed that there was typically more oral discussion, since team members had already reached a consensus on the concept map and were aware of its structure. The few new actions were typically performed by the *spokesperson* or *delegated* in the team.

For the goal of *equality of contribution* (A2), we observed a different situation. The contributions to the product of *Activity 2* only included the portion of actions that changed the previous map from its state at the end of Activity 1. The number of groups with high *equality of contribution* for both *Activities 1 and 2* (Gini index < 0.4) was 18 and 17 out of 40 respectively. A deeper analysis of both *participation and contribution* showed that groups where students participated more equally also tended to produce final products with parts added by all group members (Corr. 0.509). These results can be useful for the teacher to have an overall view of groups' equality. The teacher commented that, for further tutorials, "*this is an interesting result,… [next time] I should emphasise and make sure that everyone is fine to use the tabletop and include their ideas to minimise the non equality aspect*". However, other groups' strategies can be also valid. We observed during the tutorials that some groups agreed that they all were going to discuss the topic and only one student would perform the physical actions. This brings up the limitation of what can currently be captured by the tabletop and what cannot. The teacher cannot be present with each group but can infer the levels of learning from students' discussions. Previous work on tabletops used basic automatic speech detection in enclosed settings [18]. In the near future, new technology may capture this aspect of group work to study and support collaboration in the classroom.

Adherence to the class script

The design intended that both activities associated with the use of the tabletops would take similar time, permitting the teacher to explain and encourage reflection between and after these (Table 1, rows B1, B2). Multiple factors can affect the time actually taken by the teacher to move from one phase to the other, even when tabletops can help to coordinate the enactment of the script. For example, different groups may work at different rates, some students arrive late, ask the teacher more questions, or the teacher can just take more time explaining key points [6]. Timing differences can have serious effects on students' learning experiences, especially if key phases need to be skipped when the class ends and students must leave. Interactive tabletops, orchestrated through our system, can help teachers monitor the actual enactment and assess whether the script was followed in the classroom. Figure 7 shows the planned script for the learning activities (upper line): 10 minutes (') for initial explanations, 15' for each tabletop activity (blue lines), and 5' for each reflection phase, between and after the tabletop activities. Results over the 14 class sessions are shown underneath. For the initial explanation, the teacher took slightly longer than planned (mean of 11', against planned 10'). *Activity 1* and the reflection before *Activity 2* matched closely with the design (mean of 15' and 5' for most of the sessions respectively). However, the time for *Activity 2* was shortened in most of the sessions to 11'. This partly caught up time from the initial explanation and also gave a little time for students to share and reflect about what they did in the classroom (7') forcing the teacher to use more time than the 50 minutes allowed. This had an impact on the learning experience as it was explained by the teacher: *"Even when Activity 2 was the most interesting from a learning perspective, I couldn't make Activity 1 shorter because Activity 2 depended on what they did in Activity 1."* This may be acceptable for the teacher if time initially allocated for *Activity 2* (11' instead of 15') still allowed enough time for students to complete the task. If this information is available after the first classes of the week, the teacher could revise the design for future tutorials or for other tutors. The teacher suggested a possible re-design of the tutorials script: *"This is a very good reminder... maybe the structure for the next tutorials should be changed to give more time for Activity 2"*

Another potential group issue that can be detected from the students' application logs is whether the time allocated for the activities was enough for the students to complete the goal (Table 1, Row B3). Figure 8 (left) shows the relationship between time (average time for *Activity 1* = 15 minutes, std=1.3) and the number of links (or propositions) created by the 40 groups for *Activity 1*. Most groups started creating links by minute 5, and finished with an average of 20 links in their maps. The teacher had expected that all

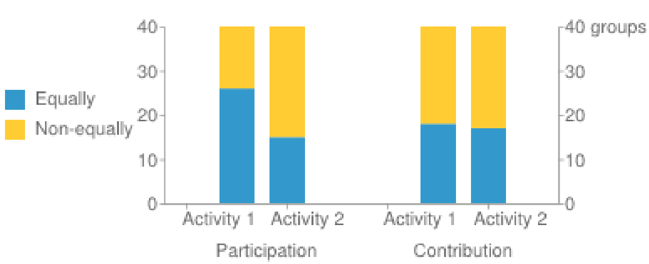

Figure 6. Proportions of groups in terms of equality of physical participation and contribution for activities 1 and 2

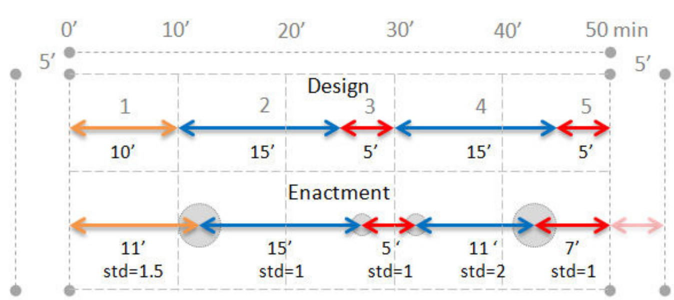

Figure 7. Comparison between the planned time limits and the enactment of the design for the 14 tutorials.

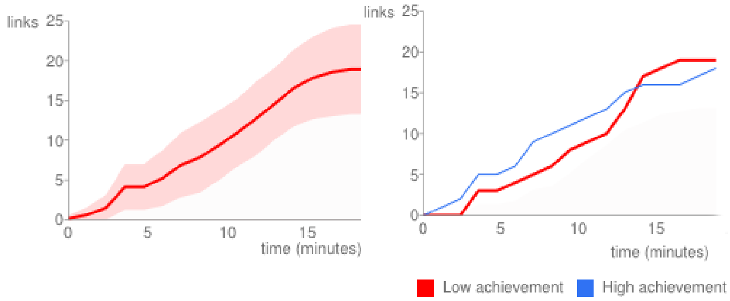

Figure 8. Left) Relationship between time and number of links created by the 40 groups for Activity 1. The shaded area represents the standard deviation. Right) Relationship between time and number of links created comparing high and low achieving groups.

groups would get started much faster than they did since there was no previous experience with this concept mapping activity in the classroom. Figure 8 (right) shows the *time- versus number of links*, comparing high achieving groups with low achieving groups. For measuring the level of achievement, each student map was assessed by counting the number of propositions matching the teacher's master list of crucial propositions for *Activity 1*. Groups were rated high achieving if they had more than 50% of these crucial propositions. This analysis suggests the low achieving groups took longer to get started. The high achieving groups started to create links in minute 1 and kept adding them at a constant pace (blue line in Figure 8, right). By contrast, low achievers only started creating links in minute 3 on average. This gives a weak statistical difference ($t(16) = 1.8$, $p < .087$). The teacher responded that, even when it can be possible to find some trend between groups that start building the solution late and their low final outcome, it is not possible to generalise the cases. "*It would be more valuable to get this information per each group during the tutorials*". A striking feature of these graphs is that the rate of creation of propositions appears to be rather steady over the first 15 minutes, the time allowed in the design. This is valuable information for the teacher's reflection on their design, even if the time constraints of the class make it challenging to perform big changes on the original plan.

Learning outcomes for activities 1 and 2

The goal of *Activity 1* was that groups should *identify the key concepts* of the topic and *their relationships or links* (Table 1, row C1). At the same time groups should not have *irrelevant concepts*. To measure this, each group map was compared with the teacher's map. This listed the concepts and links that were crucial to solve the case. Results showed that the 40 groups added an average of 50% of teacher's concepts (std=.15), meaning they missed half. In terms of essential links, 60% (std=.30) of group maps' links matched with the master map's. The number of *non relevant concepts* added was also high. The 60% (std=11) of the concepts students added were not essential concepts. Without expert analysis, we cannot conclude that these were not relevant. But in words of the teacher, "*this indicates a lack of knowledge from some students. More training is needed for students to understand how to differentiate what is important from what is not in a case*". This suggests the potential value of a new functionality that would provide the teacher, in real time, overview comparisons of *desired* and *actual* maps. This information may enable the teacher to react and adapt the strategies of the activity. For example, in this case, the teacher mentioned that "*one possible strategy to make them look at the case more carefully would be to have a sort of punishment for including non relevant information*".

Also in *Activity 1*, groups should have represented the power distribution of the key concepts by choosing a hierarchical reference between two options suggested by the teacher: concentric or linear/top-down (Table 1, row C2). This means that the player within the company with the highest level of power (the CEO in the case study) should be placed either in the centre or by one of the sides of the tabletop. The analysis showed that 18 groups chose the concentric hierarchy, 16 a linear one, and 4 did not show any hierarchical arrangement. Figure 9 depicts examples of a concentric hierarchy *(left)*, and a top-down hierarchy *(right)*. From a learning perspective, both types of hierarchy can correctly represent the levels of power. Results showed that groups that chose the concentric arrangement were partly correlated (Corr 0.4) with higher levels of equity of participation (low Gini factor). This was informative for the teacher to re-design future tutorials, and it was expressed as: "*now that I know there is some relation between layout and participation, next time I would ask students to use a circular layout*".

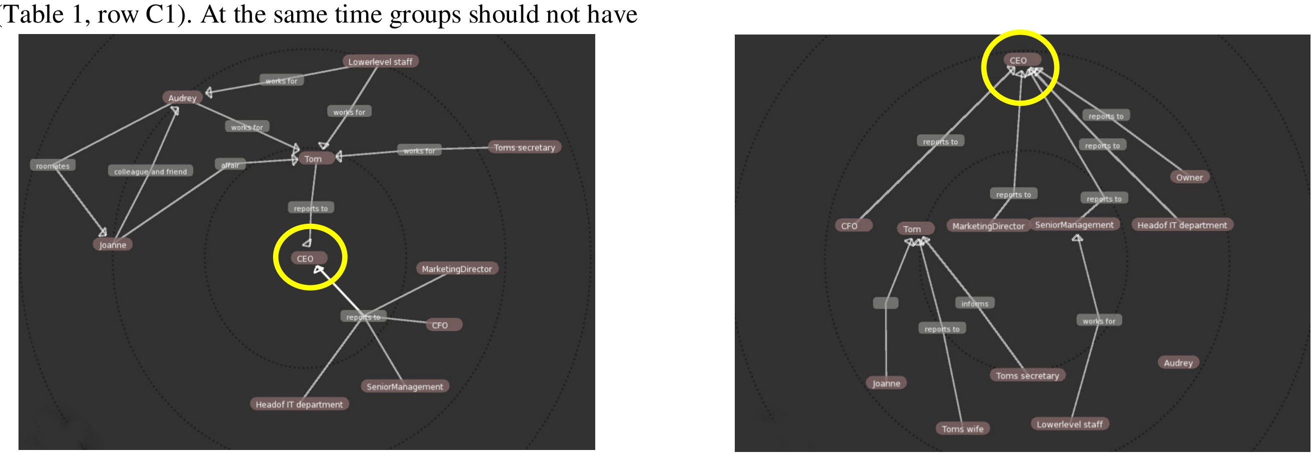

Figure 9. A) Concentric map arrangement. B) Linear map arrangement. The yellow circle indicates the most general concept.

DISCUSSION

The system presented in this paper aims to help a teacher design collaborative learning activities for students in authentic classroom tutorials. It also enables the teacher to orchestrate the activities during tutorial sessions, in real time. At a different level, the system offers functions to capture and centralise rich information about students' actions. This can be used in two ways. First, the real time and carefully curated information is displayed to help the teacher run the class. Secondly, the full data are made available for post-hoc analysis; this enables the teacher to assess the design and perhaps re-define it. We now summarise the outcomes of the enactment and our analysis.

Interactive tabletops can give teachers new ways to address challenges in orchestrating an 'authentic' classroom. Our study is in line with previous work (such as [1, 7]). We demonstrate that interactive tabletops, combined with other technologies, can give the teacher both enhanced control over, and improved awareness of, the multiple groups of students in a real classroom. Our work goes beyond previous research by providing mechanisms for the teacher to evaluate their classroom activity design, based on what actually happened in the enactments, as found in the data that can be captured by the interactive tabletops. Our design of the orchestration functions (e.g. freezing the tabletops, broadcasting messages to all tabletops, and flow control) primarily addressed needs that the teacher identified; we also took account of previous work [1, 19]. This gave opportunity to develop an environment for classroom orchestration and focus on the tools and data to help design, monitor and assess the authentic classroom activities.

Interactive tabletops, and relatively simple technologies, can be used to capture sufficiently rich data to allow teachers monitor the effectiveness of such classroom orchestration. This is aligned with our work showing that even simple interaction data could be useful for teachers to evaluate group work and performance [12,17]. Interactive tabletops can help teachers monitor the effectiveness of their design by reflecting on data about groups and class performance, such as the rate at which propositions were created. In the classroom, there are many factors that can affect the enactment of the teacher's plans from one tutorial to the next. Our approach proved helpful in enhancing the teacher's awareness of the execution of each tutorial. For example, for the timing problems found, the teacher commented: "*These results are very good as a reminder that the structure for the next tutorials should be changed to give more time for activity 2 and final take away message. Ideally by making activity 1 shorter or making some variation in the activity itself*".

Interactive tabletops can address real classroom orchestration problems that could not be addressed without this technology. To justify use of interactive tabletops, they need to provide useful services that are not otherwise possible [5]. The classroom activity, the system's functionalities and information provided should be adapted or designed according to teachers' learning intentions. The classroom activity, and more specifically, the orchestration commands, should be provided to the teacher under their request. In our study, the options to freeze the tabletops and control the flow of the whole class were specifically requested by the teacher. Similarly, the teacher valued the understanding she gained about the class enactment, information that the teacher would not normally have. This is exemplified by one of teacher's comments on reviewing the results: "*I could probably know if the groups are working too slow[ly] but I wouldn't know straight away if they are introducing the 'important' concepts*" (from the teacher's master map) or if "*the contribution is lower for some students*".

Our approach includes generic features (e.g. some orchestration and data capture functions can be used in other contexts), customisable features (e.g. the orchestration tool and some classroom indicators), and features specific to the domain of the activity (e.g. concept mapping). Choosing the right tabletop learning application depends heavily on the subject and particular learning goals. In our case, the teacher considered that concept mapping was suitable for a management case-study solving activity. Concept mapping has long been used in many learning contexts. This indicates that our system is likely to be useful for many other domains and contexts. The indicators of *collaboration and equality; and adherence to the class script,* can be generalised to other contexts. For other types of activities requiring different learning software, the indicators of *learning outcomes* would have to be identified accordingly. Further research should be done to define the levels of generalisation of available tools for classroom orchestration among various contexts.

CONCLUSIONS AND FUTURE WORK

Interactive tabletops offer new affordances for collaborative learning activities. They are progressively making their way in a wide variety of learning settings, such as group work rooms, training centres and schools. This paper describes an authentic case, a multi-tabletop system and the data analysis that show some challenges of orchestrating classrooms. Our goal was two-folded. 1) To propose an approach to provide support for teachers to design and orchestrate classroom activities with multi-touch tabletops. 2) To exploit the affordances of these devices to assess this design and promote reflection by analysing activity data captured during the enactment. Our approach was tested in a series of 14 authentic tutorials where students engaged in a collaborative activity that was part of their normal curriculum. This work can serve as a foundation for future richer analyses of data that draw upon different sources, more devices and tools involved in the classroom, with multiple sessions, and combinations of physical and virtual interactions. The next step in this research includes the evaluation of different ways to visually represent information about groups' performance, for example in private for the teacher, or at a wall display to lead class reflection. We also aim to explore the rich data that can be collected to analyse the collaborative interactions and look for patterns associated with high or low achieving groups so that these can drive alerts to the teacher in real time about potential problems in the classroom.

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