Tables in the Wild: Lessons Learned from a Large-Scale Multi-Tabletop Deployment

Ahmed Kharrufa[1], Madeline Balaam[1], Phil Heslop[1], David Leat[1], Paul Dolan[2], Patrick Olivier[1]
Newcastle University[1], Northumbria University[2], Newcastle upon Tyne, United Kingdom
{ahmed.kharrufa,madeline.balaam,philip.heslop,david.leat,Patrick.olivier}@ncl.ac.uk,
paul.dolan@northumbria.ac.uk

ABSTRACT
This paper presents the results and experiences of a six-week deployment of multiple digital tabletops in a school. Dillenbourg's orchestration framework was used both to guide the design and analysis of the study. Four themes, which directly relate to the design of the technology for the classroom, out of the 15 orchestration factors are considered. For each theme, we present our design choices, the relevant observations, feedback from teachers and students, and we conclude with a number of lessons learned in the form of design recommendations. The distinguishing factors of our study are its scale (in terms of duration, number of classes, subjects, and teachers), and its 'in-the-wild' character, with the entire study being conducted in a school, led by the teachers, and using teacher-prepared, curriculum-based tasks. Our primary contributions are the analysis of our observations and design recommendations for future multi-tabletop applications designed for and deployed within the classroom. Our analyses and recommendations meaningfully extend HCI's current design understandings of such settings.

Author Keywords
Tabletops; collaborative learning; classroom orchestration.

ACM Classification Keywords
H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—collaborative computing

INTRODUCTION
Deploying tabletop applications that have been designed for a single group in a multi-tabletop classroom setting is a non-trivial exercise. Extending designs that have been developed and refined using single group studies to a multi-tabletop classroom setting raises many issues with regards to classroom level-usability even where the single group designs have actually been tested 'in the wild'. Given that a common vision for tabletop technologies in education is as a classroom technology, our work calls for a deeper examination of the problems that can surface in such deployment contexts.

A number of guidelines and systems exist that address the design of collaborative learning applications around tabletops [13, 15, 20, 22]. However, when considering extending the application of such systems to multi-tabletop classroom environments, there is only a relatively limited amount of prior work to build upon [1, 10, 16, 18]. Testing technology in the classroom is not always possible and, when possible, is time intensive. Therefore, 'getting the design right' with as few classroom-based design iterations as possible, is crucial.

Figure 1: Multiple tabletops classroom session.

We report our investigations of the design and deployment of multi-tabletops in a real-world classroom context. Our study was conducted in a school for six weeks (which involved overcoming a number of organizational and logistical problems) with two mixed-ability classes, five different teachers of varying levels of experience (in teaching and technology use) teaching three different subjects. Most of the table-based tasks were prepared by the teachers themselves and were related to the subject topic being taught at that point in time in their curriculum plan. Either 6 or 7 SMART tables were used in each class (session) with 2-4 students working around each table (Figure 1). Two collaborative tabletop applications incorporating topic specific teacher-prepared tasks for problem solving and collaborative writing were used.

Our aim here is to contribute to HCI's limited understanding of the design (and other) challenges for the realistic context of our study (multiple tabletops in a classroom at school and lead by teachers in contrast to single tabletop studies), with the goal of presenting our experiences such that future researchers can take account of the numerous factors we identify in their designs.

ORCHESTRATION

Small groups supported by technology in undertaking collaborative learning in the classroom have received relatively little attention in the HCI research community [5, 3]. The work of Dillenbourg et al. [7, 8] on orchestration identified this gap where in [8] they defined orchestration as "the real time management by a teacher of multiple learning activities within a multi-constrained environment". The framework detailed in Dillenbourg and Jermann [7] provides a useful basis to guide both the design and the analysis of collaborative technology for the classroom.

Orchestration, however, does not apply, at the same level, to every type of technology in the classroom. For example, reading eBooks or doing web search on PCs in a networked environment does not fully lend itself to an analysis in terms of orchestration. Instead, orchestration technologies are characterized by being designed for classroom life usually involving face-to-face activities, being activity (rather than document) centric, focusing on usability by the teacher, and involving technologies that make the practice of managing the classroom manifest in physical actions with consideration to the physical layout of the technology inside the classroom [7]. Dillenbourg and Jerman's [7] orchestration framework includes 15 factors: leadership, flexibility, control, integration, linearity, continuity, drama, relevance, physicality, awareness, design for all, curriculum relevance, assessment relevance, minimalism, and sustainability. A number of developers have gone on to use this model to different extents to guide the design of tabletop technologies that support small group collaboration in the classroom [9,16, 17, 18].

Bielaczyc [2] introduced a social infrastructure framework which includes guidelines for the design of technology in the classroom. She proposes that "Only by understanding the critical variables involved is it possible to develop a deep understanding of how and why things work". The framework classifies the design elements according to four high-level categories: (a) cultural beliefs, (b) practices, (c) socio-techno-spatial relations, and (d) interaction with the "outside world". The orchestration framework [7, 8] has much in common with that of Bielaczyc's framework but it is articulated at a finer level of detail. Indeed, the 15 design factors identified in Dillenbourg and Jermann [7] fit well into the practices, socio-techno-spatial, and integration with the outside world dimensions of the social infrastructure framework.

RELATED WORK

There is a wealth of existing research on developing systems for tabletops in the form of general design guidelines [19, 21] and for collaborative learning [14, 20, 22]. However, when it comes to studies evaluating multi-tabletop environments, there is a much smaller body of published research, which primarily relates to just three research projects that encompass this topic, SynergyNet [1, 18], TinkerLamp [9, 10], and Martinez et al. [16, 17].

Dillenbourg and Evans [6] presented an in-depth analysis of the relation between tabletop technology and teaching and learning processes. They proposed a number of issues that designers of tabletop systems should take into consideration, ranging from user interaction to socio-cultural context. Similarly Higgins et al. [12] provided a literature-review-based analysis of the key design features and capabilities of multi-touch tables for collaborative learning, identifying both properties of the underlying technology and design and the effect of these on use in the classroom. Both reviews conclude that tabletop technology does have the potential to offer significant benefits for collaborative learning at both intra- and inter-group levels. They highlighted the shortage of research on the circumstances and technological configurations that allow for utilizing the affordances of the technology, improving the educational benefits, and supporting classroom orchestration.

Do-Lenh [9], through the development of TinkerLamp, concluded that the potential of tabletops, and technology in general, to improve learning depends largely not on the inherent characteristics of the technology, but rather on the educational scenario, the crucial role played by teachers, students, and other factors such as class motivation and energy. This highlights the importance of conducting such studies in realistic environments (in schools, with students of the targeted age group, and with actual teachers). TinkerLamp [9, 10] was developed through an investigation of multiple 'tangible' tabletops in a classroom in studies where orchestration was a significant component of the investigation. However, the TinkerLamp studies ultimately focused on tangible interaction with the ecology of tangible tools it allows (including paper). Moreover, the targeted users were vocational students mostly between the ages of 17-20 years. The final system, in addition to the tangible tabletops, included additional components such as TinkerBoard, a public display for awareness and control, and TinkerKey, a small paper card that allowed the execution of teacher-specific commands at the level of a group or class.

The SynergyNet [1, 18] used an integrated classroom containing four multi-touch tables, a multi-touch interactive board, and multi-touch control desk for the teacher. The room was equipped with multiple cameras and microphones for data collection. However, the setup, was established in a room in a research facility (rather than an actual school). AlAgha et al. [1] described the system, the teacher's monitoring and control functionalities, and the overall software framework. The monitoring and control tools provided to the teacher included remote access to students' tables with the ability to intervene in students' work, distribution of learning material, monitoring of the tables, and transition between horizontal and vertical displays. Two studies with two different sets of students and two teachers were conducted. The teachers commented positively on some of the non-interfering monitoring capabilities and on the ability to show answers from tables on the vertical screen, but the observations revealed that the teachers avoided using features that remotely intervene in students' activities. The recommendations and findings from this study are preliminary as the study's primary focus was the usability of the system, and the findings themselves were based on just two sessions, for which each session involved 12 students (three students per table) and was conducted outside an actual school environment.

Mercier et al. [18], who used an updated version of SynergyNet, considered the classroom context in the light of Dillenbourg and Jeraman's [7] notion of orchestration. This study was based on three classes from three different schools of sixteen students (10-11 years old) each organized in groups of four, and considered how movement between small group and whole class interaction supported collaborative engagement. The study concluded that teacher interventions that lead to whole-class discussions played an important role in shifting student reasoning to higher levels (and that the technology itself played an important role in supporting this). However, the sessions themselves were led by two researchers (rather than school teachers) and the researchers concerned were experts both in relation to the features of the system and in relation to thinking about how the technology can integrate with pedagogy. Of course, these researchers were also fully aware of the desired outcomes of the study while they lead the study sessions. The study reported a relation between the levels of engagement and reasoning of the students and the school they come from and concluded that the culture of the school, in terms of motivation to learn, collaboration, and thinking skills, has a significant effect on the level of impact that a collaborative learning technology can have on learning (confirming similar insights from Bielaczyc [2] and Do Lenh [9]).

The work of Martinez et. al [16] is complementary to our work. Their work also adopted the orchestration metaphor with focus on teachers' awareness and control, but exploring the problem from the perspective of teachers' planning learning activities, and a resulting evaluation of how well the activities followed the plan. The studies were conducted with multiple interactive tables at a university with undergraduate management students. While the study was conducted in a realistic context, the targeted audience differ (undergraduates as opposed to high school students (aged 12 – 13)). The learning tool used in the studies was a concept mapping application. The system used supported user identification (by using depth sensors on top of the tables) with emphasis on capturing as much data on the students' activities as possible for the support of the in-class teacher orchestration tool and post-class teacher reflection on their plan and the resulting activity. The teacher's orchestration tool ran on the teacher's laptop (and made use of their previous work on designing an effective teacher's dashboard [17]). It contained a set of commands such as start, freeze/unfreeze and move to next phase. It also showed a number of visualizations of the groups' activities and the levels of participation. The findings highlighted the importance of collecting as much information as possible, and visualizing this information in an easy to understand manner, to help the teachers in the in-class and post-class control and reflection activities.

The findings and lessons learned from previous research are a valuable resource and are reflected in our suggested design requirements. However, in completing our study we contribute a real-world dimension to our understanding of how multi-tabletops can be designed for use over longer periods of time, in authentic classroom settings, for a variety of subjects, and involving actual teacher-led teaching and learning.

THE STUDY

We conducted a 6-week study with two mixed-ability year 8 classes (aged 12-13 years) in a local high school. The number of students in each session was 24 on average. The technology setup involved 7 SMART tables. For logistical reasons it was not possible to conduct all the sessions in the same classroom, and the sessions were conducted in one of three rooms depending on their availability. Each room imposed different constraints in terms of how the tables could be laid out. However, we tried to allow for maximum visual contact and freedom of movement for the teachers. Students worked in groups of 2 to 4 on each tabletop as specified by their teachers.

60 minutes were allocated for each session. In each session the students used one of two collaborative learning applications (Figure 2): Digital Mysteries [13, 14] and a collaborative writing application. Digital Mysteries is a learning tool specifically designed to support collaborative learning on the tabletop. It has been previously evaluated in a school with a number of different ability groups where students participated in repeated trials. Single table evaluations of Digital Mysteries have shown that the application was successful in achieving its goals of encouraging collaboration, increasing the probability of task related discussions, and promoting higher level thinking. The collaborative writing application used followed the same design principles of Digital Mysteries. The tasks for the collaboration writing application depended on the completion of the Digital Mysteries tasks.

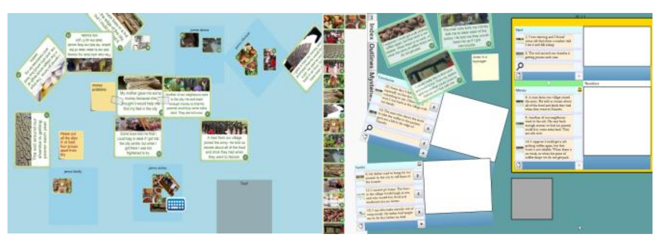

Figure 2: Digital Mysteries (left). Collaborative writing (right).

One class completed seven sessions in total in History (2), Geography (3), and English (2). The other class completed four sessions in total in History (1) and Geography (3). Both classes initially did a training session on both applications. Five teachers, who attended two 1-hour introductory and training sessions, were involved in the study and were also provided with documentation for the applications. All the Digital Mysteries tasks used were based on the curriculum subject being taught at the time. Three of the five mysteries used were fully prepared by the teachers, and the other two were prepared by a member of the research team then reviewed by the teachers.

Sessions were filmed on three cameras, one focused on the class as a whole and two focused on specific tables. Two to four researchers were present at all sessions taking field-observations and providing technical support. Interventions by the researchers were kept to a minimum (e.g. recalibrating the tables) in an effort to maintain a normal classroom environment.

The whole study was designed with the concept of minimalism in mind. Minimalism, one of the factors of the orchestration framework [7], refers to offering just the functionalities that are specific to the learning scenario and resisting the temptation to provide a fully integrated learning environment. The two learning tools used were designed with only a basic set of features that related directly to the goals of the tasks. The applications were very simple to use, and moreover, we specifically wanted to use a setup that was similar to a traditional classroom environment with tables and students collaborating around these tables without introducing new teacher tools such as visualization dashboards and special controls. Accordingly, the tables were not networked and the design relied on the teachers' own efforts and abilities to orchestrate the classroom. Our belief was that such a basic setup will help magnify any positive orchestration affordances that are inherent by the technology itself (e.g. the unobstructed visual contact afforded by the horizontal surface) and that these can be overshadowed by the introduction of 'possibly needed' control features. Though we aimed at making the design as efficient as possible while still satisfying the requirement for minimalism, this approach also helps make any shortcomings of the system more readily apparent.

THEMATIC ANALYSIS

Through deductive thematic analysis, we have identified the factors in the orchestration model that are more directly related to the design of the technology and that we have found to have the most impact on the outcome of the study. These factors are *awareness*, *flexibility*, *linearity*, *leadership*, *control*, and *cross-plane-integration*. Flexibility and linearity, and leadership and control, share a number of features in relation to the design, our observations, and participants' feedback and we have therefore further grouped these together (resulting in four distinct themes). While factors such as minimalism and physicality (the use of and movement within the physical space of the classroom) are referred to in our paper (though not as part of the main thematic analysis), other factors such as curriculum and assessment relevance and continuity, relate to external parameters such as the choice of the tasks themselves and not to the design of the technology. As such, these themes are not discussed further in this paper.

In our discussion of each theme, we briefly introduce the orchestration factors involved and our design choices in response to these factors, explore how this design worked (or did not work) in reality based on our observations, and describe the reported experiences of both teachers and students. Based on the lessons learned from the study, each section concludes with design recommendations that enable future developers to better design for orchestration. We place considerable emphasis on the views of the teacher since it is their view of whether a method 'works well', that offers a realistic indicator of whether the method has a chance of being generalized and used in practice [7]. With a study of this scale, involving 5 different teachers (whose experience in teaching ranged from 1 to 17 years), the views we collected shed light on the likely range of opinions and experiences that we aimed to uncover. Teachers' feedback was collected through semi-structured interviews conducted at the conclusion of the study and an unstructured discussion with four of the five teachers toward the end of the study. Students' feedback (7 boys and 4 girls) was obtained through semi-structured interviews with 4 groups of 2-3 students at the end of the study.

Awareness

In the orchestration model [7] awareness as a factor is presented very briefly, focusing on helping teachers become aware of the activity of the students at a behavioral level. We extend this to include teachers' awareness of the progress, quality of work, and students' participation levels.

Design: A core feature of the applications used was to encourage externalization of thinking and to make thinking visible on the table. This involved the provision of externalization tools such as named groups/paragraphs, post-it notes, and tools to make relations/links explicit in addition to encouraging the use of these tools. The application also made progressing through stages very clear to the student by providing introductory/feedback dialogs when needed at the beginning and end of each stage. The writing application maintained most of the history of the task as part of the layout thus giving a good indication of the progress and not just the current state. We targeted the awareness factor by capitalizing on the inhering visibility affordance of the large, horizontal tabletop surface combined with the application's externalization tools.

Observations: *Four girls are sitting around their tabletop. They should be grouping together evidence so that they can write a persuasive argument about why they think Jumbo is living in poverty. Instead these girls are leant over the tabletop gossiping about what they did last night and making plans for what they will do when this lesson finally* *finishes and they can leave school for the day. Taking furtive glances they are very aware of where their teacher is in the classroom. Whenever the teacher is close enough to see what they are doing they start to absentmindedly flick items of evidence across the screen.*

While the teachers did have basic training on using the application, they did not have enough time to master the skills to quickly interpret what is on the table and to determine the current stage, level of progress, or quality of the solution from quick glances on the table. Some students took advantage of such lack of awareness on the side of the teacher by making themselves look busy while they were not actually contributing to the task.

*Interviews***:** Two of the five teachers expressed lack of awareness of where the students were at the task and their level of progress. T1 expressed this by saying "*I found it quite difficult on the tabletops to work out how much they still had left to do*." Similarly, T2 said "*I think it would be useful to know when they had got to the end of the stage, and to know if they have done enough for the stage*."

On the other hand, when the students were asked about their awareness of the stage they were working at, all of the students interviewed confirmed that they were fully aware of their stage, though some reported that they were not sure of how far in the stage they have progressed. A student from group 1 said "*in the first one [stage], you would have to go all the way through and then you would have to say you are ready and you have done it. And it would say like, Stage one complete, go onto Stage two.*" Likewise, a student from group 3 said "*because after the stage when it said, it comes up with a paragraph and when you press 'okay' on your names, it tells you what stage you are up to. And then you know you are at that stage. And then once you complete that one, then you are on another stage, so it is like the tabletop puts it in sections for you, which I thought was good*."

The same two teachers expressed concerns that it wasn't easy to know which students or groups are actually working and which are just messing around, or pretending to work. According to T1 "*I think because a teacher can't see if they are messing around unless they are stood next to them...Whereas at a table, if they were screwing up statements or writing stupid answers, it would be hard to delete it.*" T2 also said that "*I felt if I was working with one group, the other groups may seem like they're all crowded round the table doing something, but actually when I got there, they'd binned everything, or they'd done something that, had I been able to visually see with bits of paper or whatever, I would have stopped them doing. But I couldn't tell, because they were using the software; I couldn't tell what they were actually doing.*"

Students' perception of the teachers' awareness of their work varied. For example, a student from group 3 said that the teacher was able to quickly identify their strategy for reading and organizing the slips by looking at the table "*as we were reading them, Mr [T3] came over and he was saying, 'That's good. I can see that you are reading them in an appropriate way.'*". A student from group 4, on the other hand expressed her concern that one student only pretended to be doing work when the teacher was near to get praise for something she has not done.

In terms of awareness of who is doing what, two out of five teachers, and students from three out of the four groups stressed the importance of the technology being able to identify the students thus letting the teacher know who is doing what and knowing the levels or participation. In T3's words "*In terms of collaboration you'd have to probably input some kind of technology that allows you to be able to identify what each student has done during the collaboration process. That's a problem that we had. Because otherwise the group exercise could be brilliant. The outcome could be brilliant. But what you find is that Tommy has done it all and Mary, Peter and Billy have done nothing.*" The students also emphasized the importance of making the teacher aware of participation.

S2: *It would be good if there was technology which showed you who used it and how much they used it, to see if anyone was slacking*.

Researcher: *Okay. How important is that to you?*

S2: *It's not really important, but it would just be better for the teacher to know*.

Interviewer: *Oh I see, for the teacher to understand*.

S1: *That everyone is contributing*.

Design recommendations: a number of design recommendations arise from our analysis:

- The ability to show simple visualization of some key performance indicators (e.g. current stage, and contribution levels - when possible) on a public display and/or a teacher private device. Moreover, it should also be possible to view the work of any of the tables on the public/teacher display. Useful resources on using a public display in the classroom for such visualization and the extent to how useful the different visualizations were can be found in [1, 9, 16, 17].
- The layout on the tabletop should clearly reflect not only the current state of work, but also the history of progress. If this is not possible, the application should provide the ability to display an easy to grasp summary of the current state with a trace of the progress upon teacher's request. This increases the teachers' awareness of the progress through the task and not just the current state. A trace of the history can also reduce the chances of students messing around. A simple application of this to our work is to keep objects thrown in the trash bin visible and retrievable rather than deleting them completely.
- It is desirable to use technology that allows for identifying the students interacting with the table. This was highlighted by both the students and the teachers. Existing

multi touch technologies (apart from DiamondTouch [4]) do not allow for user identification. Surprisingly, most work on tabletops and learning ignores this limitation completely and does not refer to it as a problem that needs to be addressed. There are some learning applications that allow and utilize user identification by using external sensing devices with multi-touch tables [15, 16], or by using pen-based tabletop technologies [13]. However, when user identification is not made possible by hardware, it can still be made possible, to a certain extent, by interaction techniques such using user tokens/color coding as a proxy for interactions. User identification can help in encouraging equal participation, regulating collaboration [13], and reducing the chances of pretending to work only when teachers are looking.

Flexibility and linearity

Linearity refers to looking at the classroom session as a simple sequence of activities which almost all students can complete at almost the same time maintaining, to a certain level, a synchronized progress through the session. Flexibility refers to allowing the teacher to override system decisions and conditions freeing the teacher from having to follow a strict instructional plan. Teachers need this flexibility to be able to maintain linearity when needed. Flexibility also refers to flexible time management which again relates to overriding the normal scenario to allow the session time to shrink or expand, or pause and resume as needed [7].

Design: Digital Mysteries used a customizable XML file to set initial goals and number of stages for the session, but this has to be pre-set before the session. Once a session starts, both applications used a strict structure that students had to follow in order to progress through the task with specific conditions that has to be met to be able to move from one stage to the next. The applications provided the ability to save/resume the session (as recommended in [7]) to give the teacher the flexibility of dividing the session into two, have breaks in the middle, and resume later.

Observations: *One of the students in the class is answering her teacher's question. As she does this, the other students sit back from their tables gazing about the classroom. The teacher summarizes her answer and then, raising his voice alerts the class "right then we have five minutes left". The students sit up, ready to do something. "I would like you in that time to focus on your groups please. I expect everyone to have groupings done in the next five minutes!" The students lean over their tables, fingers on the screen as they work together to create groups.*

Instances of teacher setting specific times to complete a stage and move to the next occurred often in an attempt to move the class forward in more or less the same pace.

Interviews: One teacher (T4) expressed the need for flexibility in terms of being able to introduce extra resources to the group dynamically to challenge the groups that are a bit ahead of others. Since the applications used had everything set beforehand, this was not possible. He added "*you've got to be able to be flexible in your teaching and change what you're doing, and the tabletops meant that that was impossible to do.*"

Three of the five teachers referred to the need for more flexibility to be able to override the strict conditions for moving between stages to help students who are struggling progress through the task, and consequently allow more control for the teacher over the flow of the session ("*you couldn't go over to a group and say, 'Well, you're struggling with that little bit. Why don't you miss that out?'*") One teacher referred to the need for 'a magic teacher button' to override system features and to freeze the machines when needed.

While the need expressed by the teachers to be able to override progress conditions might be for the goal of maintaining linearity, being able to work and progress at one's own pace was reported as one of the advantages of the system by one of the students: "*It was quite good because it is like you are only working on one stage at a time, and you don't move on until you are ready. But when you are in the classroom you move on when the majority is ready. But if you need a little more time just to read over some of the notes, then you have got that extra time.*"

Design recommendations: a number of recommendations arise from our consideration of linearity and flexibility:

- Systems must be flexible such that a teacher can change the goal of the task, or its level of difficulty for specific groups during the session based on the progress of the group. The nature of the task and the constraints of the classroom may not make this practical, but the application should be flexible to allow this if needed.
- Alternatively, the teacher should be able to set the goal of the task/difficulty level for different groups remotely before the session as part of the pre-session preparation.
- Systems must provide teacher-specific commands in addition to allowing teacher to override any conditions in the application such as the ability to force the application to move to a next stage even when the conditions have not been met. Two good examples of such tools are the TinkerKey tool used with the TinkerLamp 2.0 [9] and the teacher dashboard [16]
- Teachers should be encouraged to see activity on the tabletops as only part of their lesson plan and plan for activities (on or away from the tabletops) to occupy the groups that complete the task (or a stage) before other groups. This might not sound very relevant to the technology, but it was a requirement the teachers referred to frequently.

Leadership and Control

These two factors share many of the design issues, observations, and feedback. Control refers to allowing the teacher to be in control of the classroom, maintaining a level of interest and concentration among the students. Leadership refers to empowering the teacher to be the 'conductor' and the driver of the classroom multi-level activities in real time [7].

Design: We hypothesized that maintaining the face-to-face/unobstructed visual contact which is a core affordance of tabletop technology (combined with encouraging externalization of thinking which increases awareness, as above) is sufficient to maintain the teacher's leadership and control of the classroom. This is in contrast to a traditional computer lab where monitors can form a barrier between the teacher and the students. Due to our adoption of a minimalistic design approach, we did not have a networked environment and thus did not provide any classroom level management tools to the teachers. The assumption was that if the teacher can manage a normal collaborative classroom session around traditional desks, then the visually unobstructed nature of the technology should not notably affect leadership and control negatively or positively.

Observations: *The class is buzzing with chatter. The teacher shouts: "Excuse me year 8s. Remember, it is a privilege for you to be in here!" The students, seemingly ignoring their teacher continue interacting with their tabletops, moving elements about on the surface and chattering. The teacher loudly requests, "Can you please focus". At this the class becomes silent, but the children continue to "play" with tabletop, flicking elements across the screen to one another. The teacher attempts to remind the students of what they had done together in last session and therefore what the goal of this session is. In the corner of her eye she can see the group to her right continue to interact with their table, rather than actively listening to her. She turns towards them and they sit up straight and remove their hands from the tabletop, but the minute she turns away again the "flicking game" resumes.*

The teachers had difficulty in gaining the student's attention and in stopping them playing around with the tabletop when needed (though this varied depending on the teacher and his/her experience). The increased distractions introduced by the technology (e.g. ability to flick things around and the presence of the keyboard in some cases) did not decrease with repeated use and were a frequent source of distraction. Relying on the un-obstructed view as afforded by the technology was obviously not sufficient.

Interviews: Four of the teachers expressed feelings of having less control over the classroom caused by the technology due to lack of awareness, the technology being source of distraction, or lack of flexibility and teacher-specific control commands. T4 explained this by saying "*I agree with that general feeling of not having the control over what the students were doing at certain points. I think the SMART tables made it really difficult to manage the classroom as you might normally, because they were quite distracting for the students. Even though by the end of the project they'd used them quite a lot, they didn't really seem to be familiar enough with them to stop being able to mess around with them…*"

On the other hand, one of the most experienced teachers (T3) commented "*That [control] is a very personal thing in terms of each member of the staff you're talking to. But I think that- I've been teaching for a while now. And I think I'm quite flexible in my approach. And I can probably handle a lot of situations where perhaps a younger member of staff might feel a little bit uneasy with. And I didn't really have a problem with that. I didn't really have a problem with it at all…in terms of the overall classroom management. No. I thought it was good. I did. I thought it was okay…, I didn't really find it a problem*"

Design recommendations: Teachers' control and leadership are directly related to how aware the teachers are of what is happening in the classroom and to having the flexibility to dynamically adjust the course of the session depending on the progress of the different groups. Designing for awareness and flexibility is designing for control and leadership. The unobstructed visual contact with the students did not substitute for the need for the recommended freeze/lock command for gaining students attention [1, 9, 16, 18].

Cross-plane integration

This factor refers to the ability to move between individual, group, and classroom planes. It also refers to activities beyond the classroom.

Design: Encouraging inter-group collaboration is a main design feature of the applications. The applications allowed parallel input for most of the process (which means students can freely switch from individual to group work), but at certain critical moments (such as naming a group or a paragraph), the application disabled all interactions on the table apart from entering the group/paragraph name to encourage the students to discuss and decide on a name. Also the applications required all the students to confirm certain commands/dialogs (although this was not very effective if students cannot be identified). As for shifting to classroom level discussions, the unobstructed visual contact afforded by the technology between the teacher and the students, combined with the use of a multi-stage design should provide good opportunities to switch from group to class level activities at stage boundaries. The applications did not provide any explicit tools that allow exporting the outcome of the study in a useful form to the students, nor did they allow the integrating of external resources. In other words, the applications did not allow for moving to the 'outside the classroom' plane.

Observations: *The teacher is discussing how to make sure that each slip of evidence has been read and understood by a group when they're working together. The teacher tells the class: "This group here, they did something different, and I quite like it, because this would work for me because my memory isn't very good." The class laughs and then he* *asks the group to explain what they did. To make sure the rest of the class really understand the technique he asks everyone to leave their seats and gather around one tabletop to see the technique in action. With 24 students in the class it is difficult for each of the students to get a good view of what is going on, but the teacher focuses their attention on what works about this particular strategy through a teacher-led discussion.*

Moving to classroom level occurred when the teacher called for the attention of the class, but this was negatively affected by the lack of specific control features. Moreover, the fact that in some cases students did not progress at the same pace meant that the teachers were not always able to provide the same instructions to all the students. On the other hand, students were observed to move between the individual and group planes as required. However, there were cases where some students took over, or others refused to take part and the fact that there was not a way to identify who did what or to show participation levels, meant that such inequalities can go unnoticed by the teacher.

Interviews: As stated in the awareness and control factors, teachers expressed the need to be able to identify students to know the level of participation at the group level. Teachers also expressed the need for a tool to freeze the tables to attract everyone's attention moving the class quickly to classroom-level discussions. With regards to the conversation at the group level, and during the meeting with the teachers:

T4: *I thought some groups, the conversations they were having were really good and they were engaging. Some students picked it up really well. However, they are the students who would pick up anything really well...*

Researcher: *Have you noticed any difference in how they talk to one another?*

T3: *Difficult to access them for that*

T1: *I haven't noticed much difference, except maybe more argument.*

One of the teachers commented on the need for the application to provide a record of the outcome of the sessions for the students to take home and show that they have done well (i.e., integration with the outside world plane [7, 1]). She said that students were disappointed that they couldn't do that, and added "*I think that's an important thing because in secondary schools now they have exams every year which decides what set they're going to go into. So that work that they were examined on weren't they in their test. But they didn't have any record of it which was difficult from the teacher's point of view.*"

Design recommendations: In addition to allowing for single/parallel input and enforcing collaboration which allow for moving between individual and group planes, control tools are required for attracting the attention of all the students to help in moving to the classroom plane (Mercier et al [18] focused on this issue in the classroom, and Martinez et al. [16] focused on this from the planning perspective). The scenario described in the observations section could have been improved by the ability to project the contents of one of the tables to all the tables, or to project it to a public display while freezing the interaction with all the tables.

Improved awareness is required to know when to call for classroom level activities. The system should also be flexible enough to allow for bringing the groups to almost the same level of progress which is needed for the classroom level activities to be of benefit to all.

The design should allow for exporting the outcome of the session to the students in forms (e.g. email or printed document) useful for the students (for review, reflection, and maybe for completing the task as an assignment) and the teacher (for review, reflection, and assessment). When possible, students should also be allowed to bring their own material and use it as part of the task.

Revisiting minimalism

As noted from the concluded design requirements, there is a strong need for a networked environment to implement many of the design recommendations. Yet if a certain feature (like freezing computers or displaying the output of the table on a shared screen) can be satisfied by the existing classroom management system in the school, then there is no need for these features as part of the application. The goal is to reduce the learning curve for the teachers. It is always useful to look at the technology currently being used in the school and utilize it rather than re-implement some of its functionality.

THE COST OF 'THE WILD'

Over all, the deployment received a range of positive and negative feedback from the teachers and the students and based on our own observations. One of the most experienced teachers was very positive about the experience, its potential, student engagement, and its learning outcomes. The other four teachers (three of whom are relatively new to teaching) did not share this positive view about the study. However all teachers shared positive views regarding the future potential of tabletops as an educational technology in the classroom. The students were more positive about the experience. Using the words of one of the students "You're having fun because it's different than just writing on a piece of paper, and you're learning lots of new facts because there were lots of boxes in it." Another student answered a question about their expectations of the technology by saying "probably they were better than what I was expecting. Because, like how you could get the sticky tape and connect things together and write notes down…"

Conducting the study at this scale in the school raised a number of pragmatic issues. For each session, we had to set up the tables in the available room then remove them at the end of the session. Depending on the room, the way the tables were laid out differed. In one room which we had to use twice, the tabletops were set in spaces between desktop PCs with the computer displays obstructing the view thus removing the crucial unobstructed view affordance of the tabletops. This room also limited the freedom of movement of the teacher between the tables. Moving the tables between rooms with different lighting conditions also meant that in many cases the tables were not sensitive enough raising a number of complaints by the students. We had to recalibrate some of the tables during the session to improve sensitivity.

Another factor that was reported to have a negative impact on the study was the timing and schedule of the sessions. We had to fit a number of sessions, including training sessions, within 6 weeks. The students, therefore, had to take part in the sessions on three consecutive days during some weeks, with some of these sessions being the last session of the day, and then not do any sessions the following week. This made some the students feel bored because of the repetitive nature of the task, especially when the sessions were the last of the school day. While we have no control over the school schedule, it would have been better to aim to fit our trials in a longer period.

As for the stakeholders involved, we conducted the study with two mixed-ability classes and from our observations many of the students lacked the motivation to learn or to engage with the tasks at the tabletops. A number of students did not listen to the teachers and showed behavior issues. The teachers' low expectations of the students may have also contributed negatively. In our interviews with the teachers, T1 and T2 commented on the lack of resilience and perseverance among the students. T1 also commented that their students are "not used to properly thinking for themselves" and that they are not used to "proper collaborative work".

DISCUSSION

Extending tabletop learning applications to a multi-tabletop classroom environment raises a number of issues that are not encountered when doing single group evaluations. Many of the issues we have reported arose as a direct consequence of the real-world qualities of the study. The lessons learned and data analysis are stated as design recommendations and we re-state these here from the perspective of designers seeking to realize multi-tabletop integration of their applications. Such a perspective is distinct from that taken in SynergyNet [1, 18], for example, that focused on the framework and the class dynamics, or that of Martinez et al. [16] that focused on supporting the teacher in the classroom activity design and evaluation.

Our study highlighted the need for designing for improved awareness and, in particular, supporting awareness for inexperienced teachers. Designs should increase teachers' awareness of the state and progress of each group and the participation levels of the group members. To facilitate and promote awareness tabletop applications should:

- allow for simple visualizations of key indicators of the process. Such visualizations would typically be displayed on a public/teacher display and therefore should be simple enough to allow for a summary of all the groups [17].
- maintain a visual trace of the process history where possible. In addition to improving the teachers' awareness of progress in a task (when looking at the table) this can also help in reducing off-task activities, such as randomly creating and deleting objects, as the application will keep a visual trace of such actions.
- identify the students interacting with the table and consequently provide level and quality of participation information. This requirement has been largely ignored despite its importance (in part due to the technical challenge of distinguishing between tabletop users in multi-touch interfaces)

Working with different ability groups who progressed through tasks at very different rates underlined the need for the flexibility in maintaining more or less synchronized progress through a task (linearity). Such flexibility also means increasing a teacher's control and leadership over the students in the classroom. In addition to the progress visualizations (which increase awareness of the progress of each group), to facilitate and promote linearity tabletop applications should:

- allow dynamic adjustment of the level/goal of the task during a class.
- allow remote configuration of the level/goal for different groups as part of the pre-class (pre-session) preparation.
- provide teacher specific commands and allow teachers to override application decisions and conditions.

To facilitate and promote cross-plane-integration, tabletop applications should:

- allow for switching between parallel and single modes of interaction.
- support transitions to classroom level discussions, for example by allowing the projection of the contents of one tabletop to a public display while freezing all the other tables [18] or displaying one tabletop interface on all other tabletops.
- allow the outcome of the groups to be exported into a tangible form that will extend the impact of the session beyond the confines of the classroom.

Beyond the application itself, teachers need to adopt the technology as part of the classroom activity rather than considering it as 'the' classroom activity. In doing so, teachers practices can extend beyond the limitations of the technology itself and provide the resources needed to fill in where technology falls short.

CONCLUSION

We present our experiences, lessons learned and recommendations from a large-scale multi-tabletop deployment in a realistic context. Our study highlighted the challenges and issues that application designers and developers need to consider when extending single-group tabletop designs to a classroom environment. It also highlighted the importance of testing classroom level technologies in realistic settings, in particular, with actual teachers of different levels of experience and with students of different levels of ability.

The two factors that had the most impact on the outcome of the study were *awareness* and *flexibility*. In addition to their intrinsic importance, these factors also relate to other elements in the orchestration model including leadership and control, linearity, and cross-plane-integration. When developing a single tabletop application there is a real risk that many of these will be either inadequately addressed or completely overlooked. Regardless of how well such a system performs in a single group scenario, designers must also consider how well their systems perform with regard to different orchestration factors and awareness and flexibility in particular.

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