Towards a Teacher-Centric Approach for Multi-Touch Surfaces in Classrooms

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ABSTRACT
The potential of tabletops to enable simultaneous interaction and face-to-face collaboration can provide novel learning opportunities. Despite significant research in the area of collaborative learning around tabletops, little attention has been paid to the integration of multi-touch surfaces into classroom layouts and how to employ this technology to facilitate teacher-learner dialogue and teacher-led activities across multi-touch surfaces. While most existing techniques focus on the collaboration between learners, this work aims to gain a better understanding of practical challenges that need to be considered when integrating multi-touch surfaces into classrooms. It presents a multi-touch interaction technique, called TablePortal, which enables teachers to manage and monitor collaborative learning on students' tables. Early observations of using the proposed technique within a novel classroom consisting of networked multi-touch surfaces are discussed. The aim was to explore the extent to which our design choices facilitate teacher-learner dialogue and assist the management of classroom activity.

ACM Classification: H.5.2 Information Interfaces and Presentation: User Interfaces. User-centered design.

Keywords: multi-touch tabletop, remote access, classroom.

INTRODUCTION AND MOTIVATION
The potential of multi-touch tabletop computers to enable groups of people to simultaneously touch and manipulate a shared tabletop interface provides new possibilities for collaborative learning. Although many research studies have explored learning around multi-touch tabletops, most of them focused on the dialogue and collaboration between learners, and almost exclusively they examined single tables used in isolation. Little attention has been paid to integrating multi-touch tabletops into the fabric of classrooms and the influence they could have on both teachers and learners during in-class activities. At the core of any classroom environment is the teacher-learner dialogue which is essential to enable a social pedagogy and provide interactive learning approaches. However, little is known about how to design and operate interaction techniques that enable teachers to communicate, manage and monitor learners' activities around multi-touch tabletops.

To highlight the significance of the desired teacher-centric approach, Figure 1 represents our vision of a tabletop-based classroom in which the teacher and students work on multi-touch tables and collaborate on learning tasks. In such an environment, the teacher works on a separate table and needs to communicate with the students' tables. Centralized control and management techniques are important to enable the teacher to manage the learning task and to maintain awareness of collaborative activities. Examples of required administrative tasks include remote access to students' tables, distribution of learning material, undisruptive monitoring of student activity, transition between horizontal and vertical displays, and the ability to intervene in group work. Such a level of interaction produces various challenges as it is not clear how to extend the multi-touch surface to enable remote access, content management and interaction with multiple students' tables simultaneously. As yet, there is no clear base for design considerations of teacher-led activities that take into account the unique properties of tabletop displays.

If multi-touch surfaces are to be successfully integrated into classrooms, the importance of the teachers' role should not be underestimated since the teacher is the main orchestrator of the education process. This paper explores the educational benefits of networked multi-touch surfaces by creating a technology that integrates with traditional classroom environments. The purpose and contributions of

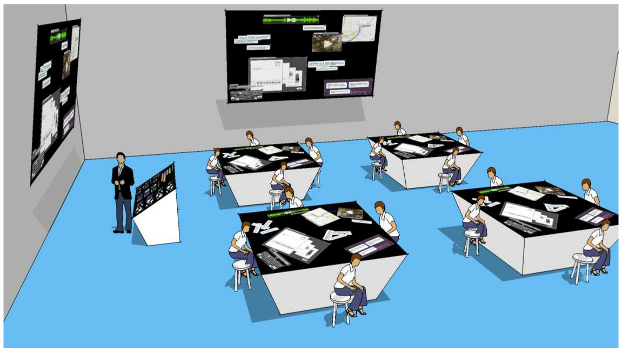

Figure1: Tabletop-based classroom environment.

this work are as follows:

- To discuss a set of practical challenges and design issues, informed by our experience and by an analysis of prior research, that need to be considered when designing a teacher-centric approach for remote control and management of group activities in classrooms using interactive multi-touch surfaces.
- To present an interaction technique, called TablePortal, which reflects the design choices to facilitate teacher-learner dialogue and enables teachers to reach, manage and monitor students' tables in a user-friendly, intuitive and efficient manner.
- To report our preliminary experience and observations of integrating multi-touch surfaces into a novel classroom environment to run collaborative learning tasks. The aim was to investigate the impact of our design choices on teachers' pedagogy and on students' participation in group activities and their attainment in specific tasks.
- Through the discussion of the implementation phase, we introduce SynergySpace, the open-source software framework we developed and used to enable rapid development of visually-rich and networked multi-touch applications for educational use within classroom environments.

The rest of this paper is structured as follows. Related work is reviewed before the design principles of the proposed technique are outlined. We then explain the TablePortal technique and discuss its affordances. Early observations of using the proposed technique in a multi-touch based classroom are discussed and results are analyzed. Finally, we draw conclusions from our research and discuss future work.

RELATED WORK

This section starts by reviewing research exploring the potential of multi-touch tabletops in education. Then, related research on distributed tabletops and reachability techniques is reviewed to explore the challenges involved and to compare it with our work.

Multi-touch tabletops in education

Although multi-touch tabletops have been extensively explored for a variety of uses, the majority of research is concerned with investigating the potential of tabletops and developing interaction techniques [e.g., 4]. Recently, there have been some investigations into the use of multi-touch tabletops in education and their ability to facilitate collaborative learning. For example the StoryTable project [5] encouraged children to work collaboratively to develop narratives. Other research has investigated the use of interactive tabletops to support children conducting collaborative design tasks [9, 18, 8], learning with a mind-mapping application [6] and collaborative Web search [15]. These studies indicated that multi-touch tabletops, while being enjoyable and engaging [e.g., 6, 18], did not always produce significant learning gains [e.g., 6, 9]. Other studies found that tabletop surfaces support equitable participation in learning situations [e.g., 16].

While the focus in most previous efforts was the collaboration around single tables that are often used in isolation, the potential of networked multi-touch tables to support social pedagogy in classrooms remains largely unexplored. Although previous research in computer supported collaborative learning has proposed techniques to facilitate teaching in classrooms using different interactive devices or communication tools [e.g., 19, 1], none of these approaches, to our knowledge, have explored the challenges and affordances of using multi-touch tabletops in real educational settings.

Multi-display environments and remote interaction techniques

Much research over the past decade has explored interactive surfaces, multi-display environments, and rooms for collaborative activities. Most have focused on advancing the shared usage of electronic whiteboards and vertically projected screen spaces. Projects like i-Land [17], PARC's Colab [22] and iRoom [13] all explored environments in which tabletops and walls were used in a distributed manner for collaborative and individual activities. These projects cannot be directly applied in classrooms because they assume fairly symmetric relationships between individuals in their work environments and that they all have similar roles and capabilities. However, teachers and learners in classrooms have different roles and responsibilities and thus they need to have different technological capabilities available to them on tabletops.

Some efforts proposed table-centric approaches where the interaction with multiple remote devices is done solely from an interactive tabletop. For example, the MultiSpace system [7] allows users working around a shared table to transfer an object to a connected laptop or a wall display by dragging it onto an appropriate portal in the corner of the tabletop display. However, it does not enable remote access and direct manipulation with objects that exist on remote devices. Wigdor et al. [28] explored the use of miniature views where a remote environment is displayed in a scaled format in the working area, and manipulations within the scaled view are transferred to the original space. Although our approach is similar in terms of using the down-scaled views to present students' tables on the teacher's table, it has a different design goal. In [28], users collaborate around a single table to control a set of wall-displays, but our work focuses on managing and monitoring group activities on other tabletops, particularly in a classroom environment.

The portal-based approach adopted in this paper has been inspired by existing efforts which employed portals or radars to interact with distant areas or displays (e.g. [3, 26, 2]). Our work builds on these efforts and aims to particularly adapt the portal-based approach for a classroom scenario and explore its potential for teaching and learning over multi-touch surfaces.

Several projects tried to link tabletops for remote and mixed presence collaboration [e.g., 11, 25]. In these projects, two or more displays are linked together to provide a shared interactive workspace. These systems share a common goal: to support remote or mixed presence collaboration over a shared workspace. They mainly address interactions with a single workspace that is shared among multiple tabletops. However, when it comes to interaction between a single tabletop and a group of tabletops, such as the interaction between a teacher's table and students' tables in a classroom, there is not yet a base or standard for the creation and design of interfaces and there are many unresolved challenges. For example, it is not clear how to access, view and lay out multiple tabletops through a single tabletop. Reachability, orientation-differences and precise selection on remote tabletops all are important issues that also need to be addressed.

Several tools have been proposed to enable classroom management or remote control such as the commercial SMART Sync classroom management software [21] and remote desktop applications. These tools, however, operate in environments involving desktop computers using a cursor, mouse and keyboard based interaction paradigm, and thus they lack support for multiple users and natural means of interaction. They also do not address the unique properties of tabletop displays such as orientation differences and support for face-to-face collaboration.

DESIGN PRINCIPLES

Our goal is to develop a remote interaction technique to enable the teacher to manage and monitor the activities on students' tables. These capabilities should be provided through a simple interface metaphor that is intuitive and easy to use. In what follows we present a set of design principles and functional requirements which take into account the classroom structure shown in Figure 1 and the unique characteristics of interactive tabletops.

1. Simultaneous interaction with multiple tables: the technique should support flexible ways to access, monitor and lay out multiple students' tables simultaneously through the teacher's table. The teacher should also be able, remotely, to collaborate or intervene in a group activity by interacting with content on a students' table using natural gestures. The main challenge addressed here is how to bring the students' tables inside the teacher's table while supporting all multi-touch affordances for both.

2. Information Transfer: The technique should support a flexible transition of learning material inside the classroom. The teacher should be able to transfer learning content between his/her table and any student table, between two or more student tables, and between a student table and a vertical display. The transfer process should be done through a natural and easy to use interaction technique.

3. Detailed exploration and precise selection on students' tables: Accessing and viewing the students' tables simultaneously through a single display may result in large sets of displayed data or densely packed regions. Such packed visualization can impair comprehension of information or disable precise selection of small targets on remote tabletops. The fact that most interactive tabletops rely heavily on touch-sensitive input complicates the situation as fingers can be much larger than the data to be manipulated. Thus, remote access to students' tables should allow for more detailed interaction by providing fixable navigation and zooming techniques that allow the teacher to explore and interact easily with areas of interest on the students' tables.

4. Resolve orientation conflict between teacher and students: As mentioned earlier, remote access to desktop environments does not tackle different orientations of content and it assumes that both remote and local users will experience the same viewing perspective. In tabletop environments, artifacts can be oriented differently due to the different physical positions of users around the tabletop. For a teacher who is remotely monitoring activities on a students' table, a view of differently-oriented artifacts may present difficulties, such as inability to understand artifacts or misinterpretation of actions performed by students [14]. Thus, adapting remote access to tabletop displays may require techniques to resolve orientation differences between users who share the view of the same content across separate displays, but who view it from different perspectives. This is particularly important for the teacher, who needs to rapidly track and comprehend from his/her own table the group activity on the students' tables. The main challenge addressed here is how to enable the teacher to monitor students' tables in real time from the right perspective without disrupting the group activity or affecting the orientation of content on the students' tables.

THE TABLEPORTAL INTERFACE

To meet the above design principles, we developed an interaction technique we called "TablePortal" to facilitate communication between teacher and students' tables in the classroom environment. It provides a portal to another tabletop, connected to the same network, that allows the user to see and interact with its content. Figure 2.a shows multiple TablePortal components, whereas each component shows a scaled-down view of the remote tabletop. The interface consists of an inner frame where the remote workspace is viewed and, on the left, a list of control buttons to operate various functions. While the TablePortal can be seen as a 'window' or a down-scaled view of the remote surface, it is also a multi-touch interactive element that can be rotated, moved and resized, as any normal artifact, by applying the widely adopted two-finger multi-touch gestures on the top bar (see Figure 3.a). This allows the teacher to quickly reposition, reorient and resize the TablePortal component to experience a new perspective of the students' table. It is also possible to simultaneously view and interact with a group of tables by launching multiple TablePortals. This enables the teacher's table to resemble a command-and-control centre with intuitive control capabilities. The teacher can connect to and manage the entire distributed environment using natural multi-touch

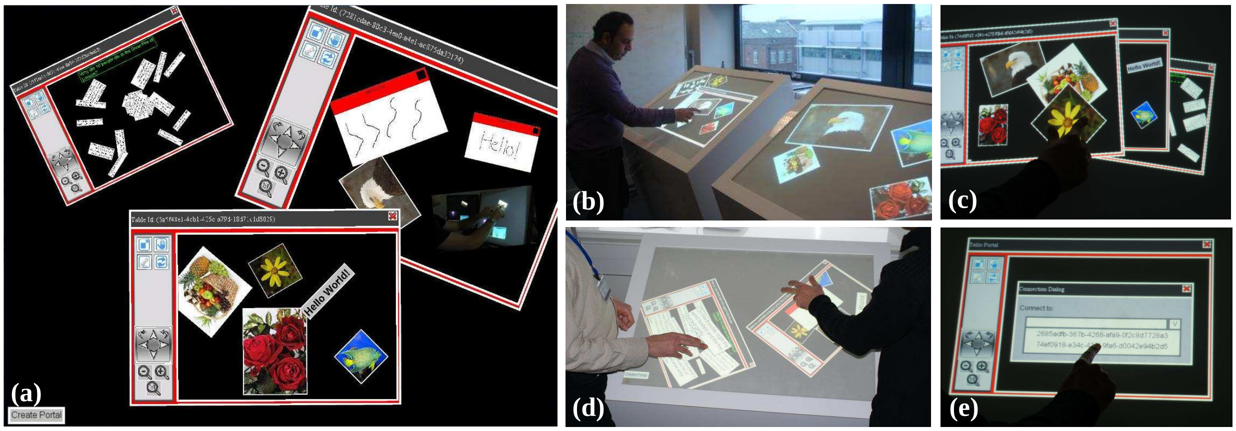

Figure 2: (a) TablePortal widgets displaying remote tables. (b) Content on remote table can be manipulated through the TablePortal. (c) TablePortals can be arranged into piles. (d) Support for multiple users accessing multiple tables. (e) A user is enabled to choose a table to connect with from a list of connected table IDs.

gestures. In addition, a large multi-touch surface can allow multiple remote displays to be arranged like organizing papers on a table. For example, a teacher dealing simultaneously with multiple students' tables can arrange the corresponding TablePortal components into ad hoc piles, so that they take up less space, or side-by-side for comparison (see Figure 2.c).

TablePortal requires the tabletop to be part of a network. When the tabletop is first launched, it requires the teacher to identity a particular tabletop to connect with from a list of IP addresses or unique names assigned to the connected tabletops (Figure 2.e). TablePortal operates in two modes: the display mode and the interactive mode, and the user can switch between the two modes using a toggle button. While the display mode allows the user to monitor the remote table without altering its content or intervening in its activities, the interactive mode enables the user to remotely interact with and modify the remote tables' content. In what follows, we introduce the affordances provided through the TablePortal interface.

1. *Real time remote interaction with remote content*: TablePortal enables the user, through the interactive mode, to interact with content on remote tabletops using the same interaction techniques available elsewhere on the surface. Artifacts can be remotely moved, resized, rotated or annotated in real time by applying the appropriate gesture on the corresponding TablePortal content (see Figure 3.b). When the user operates with the data within the TablePortal display, input events are translated as if they were operating directly on the content within the target tabletop. Also, changes applied locally on the tabletop will correspondingly apply on the TablePortal content.

2. *Detailed exploration on students' tables*: As explained earlier, the TablePortal interface provides an interactive down-scaled view of the students' table. However, the down-scaled artifacts inside the TablePortal may be too small to be properly viewed, selected or manipulated. Although the teacher can get a larger view by resizing the whole TablePortal frame, some artifacts may remain difficult to view or manipulate, especially if the original artifacts are not large enough. In addition, there may not be an extra space on the table to expand the TablePortal in order to get a larger view. To enhance reachability on students' tables, a navigation controller was attached to the TablePortal to enable full control of the remote view. It provides four functions: translate, zoom, rotate and centre. Regions on the remote display can be magnified by navigating through the remote view and zooming-in the relevant area using "+" and "−" controls, which allow the magnification ratio to be increased or decreased (see Figure 3.c). In addition, a reset button enables the user to quickly reset the view to its original status by cancelling any applied navigation processes.

Multi-touch input can still be applied on the remote content after applying any of the navigation processes. For example, a teacher can zoom-in a particular area and select an item that would otherwise be too small to touch. This

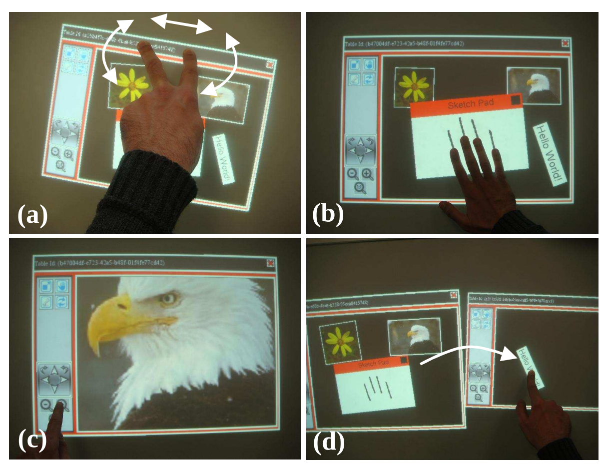

Figure 3: Interactions with TablePortal (a) Move, rotate and resize by gestures on top bar, (b) Interact with remote content (c) Navigate, zoom in & out. (d) Transfer content from a table to another.

allows fine-grained touch interaction and annotation of remote artifacts to be performed precisely at high zoom levels. All navigation actions are applied only in the inner view of the TablePortal widget, and thus they will not alter the size or position of the outer frame. This is particularly important in order to improve reachability on remote tables without the need to expand the TablePortal size and, perhaps, occlude other objects on the table.

3. Transfer of artifacts*:* TablePortal enables the teacher to transfer learning materials, e.g., digital artifacts or documents, to student tables by dragging them from the local workspace and dropping them on the TablePortal component representing the target table. The transferred artifact will be positioned on the target table exactly where it has been dropped inside the TablePortal. Similarly, artifacts can be removed from a remote students' table and placed on the teacher's table by dragging them out of the TablePortal component. Artifacts can also be transferred from one remote table to another by dragging artifacts from one TablePortal to another. Any operations applied on the artifact on the source table (e.g., zoom, rotate) will be retained on the target table (see Figure 3.d).

4. On-demand orientation-adapted view: Another feature in the TablePortal technique is the adaptable remote view that it provides, which overcomes orientation differences between the teacher and students around their tables. It provides the teacher with a real-time view of remote content that is partially adjusted to match his/her viewing needs. Artifacts within the adjusted view are reoriented to aid readability without affecting the orientation of original artifacts on the students' table. Figure 4 depicts this technique: artifacts on Table A are split over personal territories and are oriented differently to face individuals sitting around the table. Table A is being remotely monitored by two individuals on Tables B, C using TablePortal components. Since the individual on Table B is watching an identical view of the remote content, he may face difficulties in reading artifacts that do not directly face him. This can be even more difficult if artifacts are frequently moved by users around Table A. Although he can reorient individual artifacts to face him using the rotate gesture, this may conflict with users on Table A who remotely share the same content but have different viewing perspectives to it.

On the other hand, the TablePortal on Table C shows the same content but with artifacts reoriented and set to a global alignment to face the person sitting in front of the table. The user on Table C can view artifacts from the right perspective regardless of how artifacts are oriented on Table A. Meanwhile, any transformations or changes applied on the original artifacts *are still reflected* through the TablePortal view, except that the orientations of artifacts remain constantly fixed. For example, annotations, video content and movement of artifacts between personal territories can still be watched in real time.

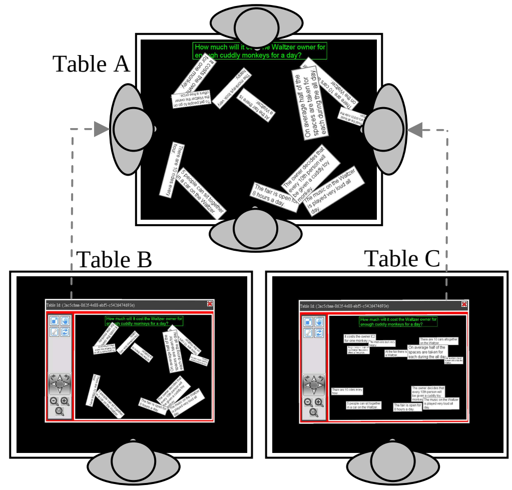

Figure 4: Real-time orientation-adapted view of remote tables using TablePortal.

The teacher can activate the orientation-adapted view on demand by setting a global rotation angle to apply on all artifacts within the TablePortal view. We emphasize here that having the software reorient objects to fit the user's viewing preferences is an approach adopted in many earlier efforts [e.g., 24] to support face-to-face or co-located collaboration. In contrast, we employ this approach to resolve orientation differences between users who share the same content over separate tabletop displays.

We are also aware that this orientation-adapted view does not reflect the exact status of the remote content, and thus it may be inappropriate for situations where a high level of natural tabletop awareness is required (e.g., mixed presence collaboration). However, it is particularly useful in situations where comprehension and readability are prioritized over awareness of other artifact's transformations. An example of such a situation is a teacher who needs to rapidly monitor or read students' hand-written notes on a remote table in real time. No matter what may be the position of students around the table, the content can be constantly viewed from the direction preferred by the teacher.

The orientation-adapted view also offers an effective solution to resolve orientation differences when linking horizontal (table) and vertical displays (presentation boards). To promote more dialogic interaction in the classroom, a teacher can select a chosen students' table and view it on a vertical wall display in order to show the whole class the solution that a particular group is working on. However, while artifacts on horizontal students' tables can be viewed from difference perspectives, a vertical display can only be viewed the right way up. Thus, content on horizontal tables may become incomprehensible if it is directly viewed on a vertical display. TablePortal enables the teacher to adapt the view of remote content so that all artifacts become aligned horizontally. The augmented view can then be shown on the vertical display by drawing a link

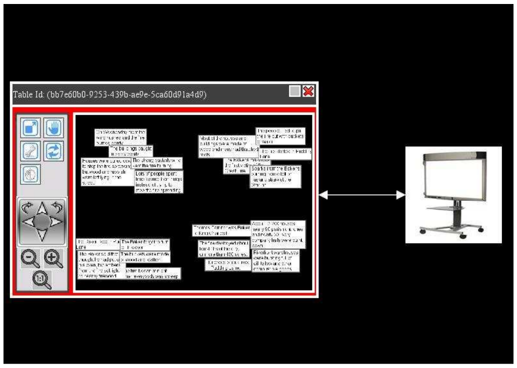

Figure 5: Transition between a student table and a wall display by drawing a link between the TablePortal and the display icon

between the TablePortal component and the icon representing the vertical display, as shown in Figure 5.

MULTI-TOUCH TABLES IN CLASSROOMS

We conducted an observational study to learn more about how teachers use the TablePortal technique to manage learning in a formal educational setting, and whether the features we included in light of our design principles were effective in real classroom activity.

The observational study was conducted in the multi-touch based classroom we built, shown in Figure 6. This environment represents our view of the futuristic classroom in which multi-touch surfaces are seamlessly integrated into the fabric of the classroom. The teacher has a lectern-style multi-touch surface (Figure 6.a) on which he/she works to manage the classroom activity with the support of the TablePortal technique. Students have four flat multi-touch tables, especially designed to have sit-to-use style (Figure 6.b). Both teacher's and students' tables are diffuse illumination (DI) based surfaces with rear-projection that, with the current vision system software, support 30 simultaneous touches. Additionally, one single-touch vertical display (Figure 6.c) is available to show material that needs to be discussed on a global basis. All tables and the vertical display are connected to the same LAN network that achieves a 10Mbps data transmission rate. The TablePortal technique will be used in this classroom to enable the teacher to manage learning tasks and monitor student activities.

Method and Task

Our classroom was used by two visiting groups from junior schools. Each group comprised 12 10-years old boys and girls with their school teacher. In each session, 3 children were seated around each of the four multi-touch tables (see Figure 7.a). The teacher worked on the lectern-style table to manage and monitor the learning task. Neither teachers nor students had had prior exposure to multi-touch surfaces.

We used 'mysteries' as a learning task in the classroom. Each mystery typically consists of 15-30 digital slips containing the data needed to solve a conceptual problem by answering an open question. Students around each table

Figure 6: SynergyNet classroom: (a) The teacher's multi-touch table. (b) Students' multi-touch desk. (c) Vertical display.

get a mystery task from the teacher, and then should use as much data as possible, from the provided artifacts, to formulate a coherent story that answers the mystery question. Artifacts can be moved, rotated and resized using the common multi-touch hand gestures.

The teacher was in charge of managing the whole class activity from the teacher's table, issuing specific sets of artifacts to specific tables, monitoring progress of the task, and giving assistance to students while they were working. Prior to the task, the teacher was given 20 minutes to interact with the table and discover the TablePortal interface and functionalities. The given instructions were deliberately kept to a minimum in order to determine the extent to which the techniques are intuitively discoverable. Children were also given a similar time prior to experiment in order to train on interacting with the multi-touch surface using a set of fun activates. Each classroom session lasted between 45 and 60 minutes and all actions were video and audio recorded. A post-task interview was conducted with each teacher.

Observations and Results

We analyzed video from the two sessions to investigate how teachers used the TablePortal widget to manage the classroom activity. We were primarily interested in how they used TablePortal's interaction metaphors in teaching and in any problems they had while using them. The focus was on teacher-student communication and overall classroom management.

Observations from the exploratory period indicated that teachers were able to discover most of TablePortal features including the interaction with the students' tables, the manipulation of the widget, object transfer and navigation through the remote view. However, they needed further instructions on how to set the orientation-adapted view.

When the learning session started, teachers began by choosing a particular mystery and explaining the problem for which the students needed to provide a solution. Teachers then distributed the mystery's content to the

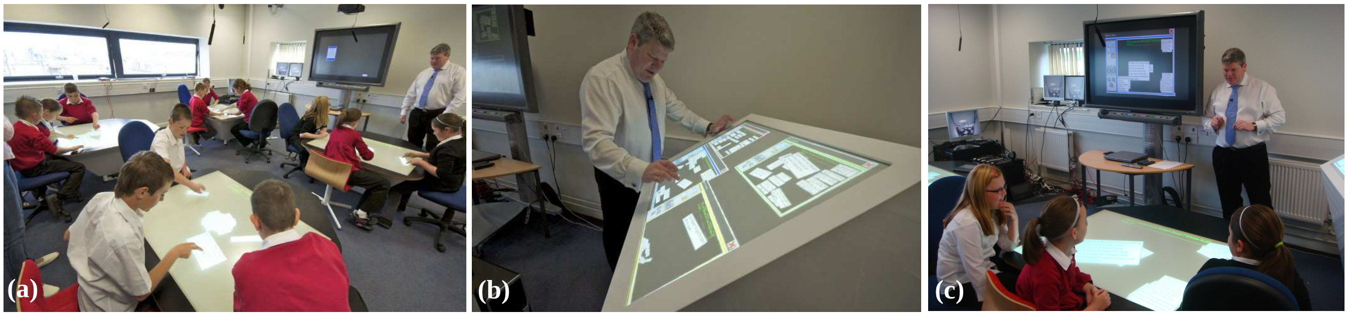

Figure 7: (a) Students are solving a mystery. (b) A teacher is using the TablePortal to interact with students' tables. (b) Projecting a students' table on the vertical display for whole class discussion.

students' tables using the teacher's control panel to send content to a particular (or all) table(s).

TablePortal to monitor students' tables

After setting the mystery's content on all the students' tables, each teacher created four TablePortal components on the teacher's table to access the four students' tables (see Figure 7.b). To enable teachers to easily map each table to its TablePortal, tables were assigned different colours (e.g., red, green, yellow and blue) and the enclosing frame of the ablePortal widget was coloured accordingly. One of the teachers aimed to make mapping easier by organizing the TablePortal components on the table so that they matched the layout of tables in the room.

While students were working collaboratively, all content transformations on the students' tables were being reflected in real time through the TablePortal components on the teacher's table. Due to the small initial size of the TablePortal components, teachers reported that most artifacts on the students' tables were unreadable through the TablePortals. Teachers resolved this by monitoring tables separately by choosing one TablePortal at a time and enlarging it to cover the whole space on the table. The other TablePortals were shrunken and kept behind so that they took up less space until they were needed. The remote content became clearly visible and reachable after enlarging the TablePortal.

A remarkable observation was the way teachers combined the TablePortal approach with their familiar pedagogy to monitor and intervene in ongoing activities. As the task progressed, teachers used a strategy of tracking changes through the on-screen TablePortals and then moving around the classroom to ensure that all students were participating. They realized that the TablePortal components show only content changes but do not show "who did what". However, the TablePortal helped teachers to monitor, in silence, what was happening at each table until they knew when and where they needed to intervene. For a teacher to know when to intervene in a group's activity is difficult to judge. Intervention too soon may disrupt discussion whereas failure to intervene when a group is having difficulty may result in pupils' becoming frustrated and going off task. Using the TablePortal to remotely monitor a group that is in full discussion is likely to encourage them to try to draw a teacher into to their conversation.

Although teachers could remotely manipulate artifacts on tables, they rarely used this facility to intervene in students' work, and preferred to visit students' tables to directly interact with content. This could be explained by the teachers' common experience of assisting students through one-to-one or small group conversations. This also indicates that the TablePortal worked as a complimentary monitoring strategy to passive listening, talking with a particular group and walking around observing.

TablePortal to mix group and whole class discussions

TablePortal also allowed a mix of group and whole class discussion throughout the learning task. It was noticed that teachers looked at all the table layouts through TablePortals, compared them with observed talk and interaction, and then selected the appropriate groups on which to focus in whole class discussion. Answers from particular tables were linked to the vertical screen to provide a focal point for class discussion, as shown in Figure 7.c. The transition from a students' table to the vertical display was controlled by the teacher using the approach shown in Figure 5. This enabled the teacher to rapidly vary the teacher-student dialogue between individual groups and the whole class.

Navigation and zoom features

There were several instances where teachers wanted to view two or more tables simultaneously for side-by-side comparison of students' solutions. However, the limited space on the table obstructed the ability to view multiple TablePortals while maintaining good readability on both. Enlarging a TablePortal provided a clear view at the cost of occluding other components on the table. Thus, teachers attempted to scale down the TablePortal widgets to provide space on the table to view multiple students' tables. After arranging the scaled-down TablePortals to match their needs, teachers tried to use the navigation controller in order to explore and zoom-in target areas within students' tables without needing to resize the whole TablePortal widget. Due to the nature of the given task, teachers had to zoom-in frequently to reach and read small artifacts, and then zoom-out to check the overall solution. This required extra time and effort from teachers to monitor the entire students' table. However, the navigation controller eventually enabled teachers to reach and read any artifact on the students' tables.

One teacher also used the navigation and zoom features in an unexpected way. We anticipated that the navigation and zoom features would be used only for detailed and precise interaction on student workspaces. However, one teacher occasionally used them while discussing students' answers on the vertical display in order to focus discussion on a specific part of the answer or to enlarge the view to make some artifacts easy to read by all students.

Orientation-adapted view

Teachers also explored the orientation-adapted view and reported that it was very useful. While monitoring students' tables without adapting the orientation of content, recordings showed teachers frequently turning their heads or rotating the whole TablePortal. Because students were moving and rotating artifacts frequently, this complicated the teacher's ability to read them. After adapting the content to make all artifacts face the teacher, they indicated that they could rapidly read and assess the students' solution. They also were able to watch other content changes by students, such as positioning, resizing or passing slips between personal territories.

Adapting content orientation was also useful when discussing students' answers on the vertical display. No matter how the artifacts were oriented on the students' tables, teachers tended to reorient content for viewing on the vertical display so that all students could read it easily.

Teachers' Responses

Overall, teachers reported that they felt comfortable using the TablePortal. Also, they did not have noticeable problems with controls. One of the teachers said that the TablePortal "enabled me to see the level and pattern of activity in different groups" and that "it enhanced the repertoire of pedagogic strategies open to the teacher". However, he indicated that the position of the teacher's table allowed children to watch things on it and this sometimes distracted those who enjoyed playing with the slips to watch them move on the teacher's table. Another teacher said that "the ability to link the TablePortal to the vertical screen allowed me to maintain an emphasis on group problem solving but to vary the size of the group from three children on one table to the whole class and back again". Both teachers declared that the children were more actively engaged in discussions with each other or with the teacher than they were while performing the same task in a traditional classroom. One teacher attributed the enhanced level of engagement to "the flexible interaction which enabled them to enlarge important artifacts for discussion and shrink those that were less important, a thing that cannot be done with the paper version of mysteries". Teachers agreed that the technique improved classroom management by enabling an immediate and non-interfering monitoring of group activities without the need to visit students' tables frequently. This eventually helped them to provide more immediate and in-dept help for students.

One of the teachers declared that the navigation and zoom functions improved teaching and discussion by varying the children's focus and their perspective. Teachers were also happy with the intuitive interface and interaction offered by the multi-touch surface, which made most aspects of the TablePortal technique discoverable and easy to use with minimal instructions. They also found the experiment enjoyable and they want to cooperate with us to adapt more elements of the school curriculum for use in the multi-touch based classroom.

Teachers also provided useful suggestions to improve classroom management and teaching using the TablePortal technique. For instance, a teacher suggested that the ability to lock interaction with students' tables would be useful as a way to enhance the transition stages of lessons. He also wanted the TablePortal to record and replay group actions to enable teachers to show the development of a train of thought, to review their teaching and to reflect on their practices.

Limitations

The experiment revealed some limitations in the TablePortal approach. First, it requires a large amount of space on the teacher's table, especially when multiple tables need to be viewed simultaneously. Second, only one TablePortal at one time can be linked and viewed on the vertical display. There were some instances where teachers wanted to show, and discuss with the class, more than one group solution on the screen. Third, the nature of the given task did not require artifacts to be transferred from one students' table to another. Thus, the ability to transfer content from a table to another was not tested by the teachers. This feature would be useful for collaborative tasks in which individuals on separate tables need to share the same content.

Although our early observations showed improved levels of classroom management and students' engagement in class discussions, further studies are required to understand the impact of centrally-managed tabletop environments on students' learning outcomes. This will be considered in our future work.

IMPLEMENTATION

When we started to think about integrating multi-touch surfaces in classrooms, we decided to provide not only a specific application but also a skeleton that would enable researchers and developers to easily link together multi-touch tables and to build a variety of rich multi-touch applications for educational use. For that purpose, we built SynergySpace [23], an open source software framework, to offer two integrated layers of software development. First, it enables rapid development of visually-rich multi-touch applications using an extensible library of OpenGL UI components. Then, it enables tabletops to be easily linked via a network and allow for the integration of various networking functionalities to upgrade the system for distributed use. For example, it allows content, such as text, video, images and documents, to be seamlessly moved from table to table. One table can establish a view of another table and see content updates synchronously. Multiple tables can share the same content-space, allowing tables to collaborate on the same task. Teachers can also view any table or view all tables simultaneously as well as engage in command-and-control activities that facilitate classroom management. All these functionalities can be used and customized in applications using an easy-to-use API. Rather than being focused on a specific application, the goal is to develop a software system that facilitates single-table collaboration and whole-classroom collaboration. The SynergySpace framework is built in Java, using native OpenGL bindings via jMonkeyEngine [12], a commercial-grade scene-graph API. Using this platform, it has been possible to use libraries that read PDFs, office documents and videos, as well as giving access to hardware accelerated audio and the Open Dynamics Engine physics system. SynergySpace is freely available for academic use, with a set of demo applications to present all the functionalities mentioned above.

We used the SynergySpace framework to render the TablePortal interface and other digital artifacts over the multi-touch surface. TablePortal utilizes network communication to access and retrieve artifacts on the remote tabletop and replicate them inside the TablePortal interface. Through the tree structure of the TablePortal, replicated artifacts are added as child components, causing any transformation of the TablePortal frame to affect the total transformation of the child artifacts. This enables users, for example, to rotate, translate or scale the whole view by applying the relevant gesture on the parent frame.

Input events applied on the TablePortal content are dispatched and applied on the corresponding remote tabletop and vise versa. This keeps the TablePortal content synchronized with the original artifacts. Each TablePortal also has its own viewport by projecting the scene inside it to the position of a virtual camera. This enables navigation through the TablePortal's content by moving or rotating the viewport's camera. Navigating through the scene replicated inside the TablePortal gives the illusion of navigating through the original scene on the remote table.

The replication of the primary artifacts inside the TablePortal interface allows to make use of the affordances provided by the primary artifact but, at the same time, adjust it by computer-supported functionality to support the viewer's needs. For example, the orientation-adapted view is achieved by applying a filter to the synchronization channel in order to mask orientation changes and then replace them with those set by the viewer. This is achieved without affecting the synchronization of other changes applied locally on the remote tabletop.

CONCLUSION AND FUTURE WORK

Research in multi-touch surfaces has advanced considerably over the last few years. We believe that there is a need to develop environments of networked multi-touch surfaces that can bring this technology to classrooms in the near future. This requires novel interfaces that can achieve a reasonable level of central management and remote access capabilities while addressing the unique requirements of multi-touch tabletop displays. The work in this paper contributes to the state of art in tabletops by exploring the teacher's role and social pedagogy when integrating multi-touch surfaces in classroom environments. It presents an interaction technique, called TablePortal, which facilitates a teacher-centric approach in classroom environments by enabling the following functional capabilities:

- Flexible monitoring and interaction with multiple students' tables through the teacher's table.
- Flexible navigation and exploration of areas of interest within students' tables.
- Orientation-adapted views to allow for real-time monitoring of remote content while context remains comprehensible and easy to read.
- Resolution of orientation problems when linking horizontal and vertical displays.
- Transfer of artifacts between tables by means of drag-and-drop.

While some of our design choices draw from different aspects of existing techniques, much of the research value is in exploring the unique requirements and design considerations of multi-touch based classrooms and the affordances of enabling a teacher-centric approach for remote control and monitoring of students' tables.

We also reported early observations of operating the TablePortal technique in a classroom of networked multi-touch surfaces. The use of the technique in a formal educational setting with school teachers and pupils helped us get a broader insight into how the multi-touch technology integrates into classroom activities and teaching pedagogies. To our knowledge, our classroom environment is the first to integrate networked multi-touch tabletops to support classroom flexibility by enabling seamless transition between teacher-led activities and students' collaborative activities. Preliminary results support our design choices and show an enhanced level of teacher's awareness, flexible monitoring, and a positive impact on the social pedagogy in the classroom. Results also reveal some limitations in our approach that we hope to consider in our future work. In the discussion of the implementation phase, we introduced SynergySpace, the software framework we built and used to implement the TablePortal, and which offers solutions to building a wide range of applications for both remote and co-located collaboration over multi-touch tabletops, particularly in classroom environments.

In our future work we are going to set up the multi-touch tables in schools to explore the potential of multi-touch surfaces in real classroom environments and the most fluid ways for students and teachers to interact with the technology and to communicate with each other. We will also investigate the development of curricula, pedagogical supports and a wide variety of learning tasks to fully integrate this technology into classrooms.

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