# Facilitating Collaborative Learning Between Two Primary Schools Using Large Multi-Touch Devices

James McNaughton[1], Tom Crick[2], Andrew Joyce-Gibbons[1], Gary Beauchamp[3] and Nick Young[3]

[1]*School of Education, Durham University, UK*

[2]*Department of Computing & Information Systems, Cardiff Metropolitan University, UK*

[3]*School of Education, Cardiff Metropolitan University, UK*

Corresponding Author:

Andrew Joyce-Gibbons

e-mail: andrew.joyce-gibbons@durham.ac.uk

tel: +441913348368

fax: +441913348311

The total number of words of the manuscript, including entire text from title page to figure legends: **6318**

The number of words of the abstract: **161**

The number of figures: **3**

The number of tables: **0**

# Facilitating Collaborative Learning Between Two Primary Schools Using Large Multi-Touch Devices

*This paper presents a technical case study and the associated research software/hardware underpinning an educational research trial in which large touch-screen interfaces were used to facilitate collaborative interactions between primary school students at separate locations. As part of the study, an application for supporting a collaborative classroom activity was created for the trial which allowed students at either location to transfer resources to the students at the other via a 'flick' gesture. Building upon previous work from the SynergyNet project, the investigation required several novel innovations to the SynergyNet framework to enable it to support synchronous remote collaboration. This builds upon previous lab-based studies which were all predicated on co-located group collaboration. The innovations on this established research software/hardware stack enabled the first successful classroom collaboration activities between two separate locations within the United Kingdom using large touchscreen interfaces and suggests that the software provides the potential for innovative pedagogic practice and collaboration which would otherwise be impossible with conventional devices.*

*Multi-touch devices, gestures, computer-supported collaborative learning, SynergyNet, networking, ICT*

# 1. Introduction

Large touchscreen interfaces offer many opportunities for collaboration between co-located learners; not only when the interface is shared but when two or more co-located interfaces are networked together to allow for the transfer of materials between them (Kharrufa et al. 2013; Kreitmayer et al. 2013). As well as presenting valuable pedagogical opportunities, the successful integration of multi-touch tables into usable computer-supported collaborative learning (CSCL) activities presents major challenges both technically and for teacher orchestration of lessons (Dillenbourg and Evans 2011).

This study starts from the viewpoint that collaborative small group learning activities have the potential to lead to substantial learning gains for the participants, more so than activities they have completed individually (Barron and Darling-Hammond 2008; O'Donnell et al. 2013). There is a clear role for appropriate technologies to support this collaboration, enabling configurations for group work and types of task which are not otherwise possible. CSCL theory and research emphasises the role of technology in supporting learner participation, knowledge acquisition (information) and knowledge creation (knowledge objects and social practices) (Lipponen et al. 2004). Much of the CSCL research base emphasises the importance of face-to-face interaction and the design of tasks to optimise the participation of learners (Stahl et al. 2014).

The growing interest in face-to-face collaboration by learners engaged in mutual negotiation of meaning (both procedural and factual) inspired the creation of the *SynergyNet* project[1] at Durham University, a UK EPSRC/ESRC-funded research project to identify important technical and pedagogical challenges in the CSCL domain (Higgins et al. 2012). Important technical challenges addressed during the project included the development of teacher orchestration tools which enabled seamless transition between individual spaces, group spaces and interactive whiteboards; these were respectively termed the private, shared and public spaces in the classroom by Dillenbourg and Evans (2008). They also identified the potential for a group to share information with other groups, building on the work

---

[1] tel.dur.ac.uk

of Everitt et al. (2009). However, in this case the mechanism developed did not involve sharing between personal devices such as computers; rather, *SynergyNet* developed tools to allow sharing seamlessly between multi-touch tables within a lab-classroom setting (Hatch et al. 2011).

The original *SynergyNet* study focused on schoolchildren aged 10-11 years old, working in collaborative groups nested within a lab-classroom. Data was collected on each group and each table as tasks were completed simultaneously. Data was also collected on the arrangement of the whole class and the teachers' behaviour whilst supporting the collaborative activity. Studies showed that compared to tasks completed using paper-based equivalents, tasks completed using multi-touch tables learners showed improved uptake of ideas (Mercier, Vourloumi & Higgins, 2015), as well as evidence of more sophisticated reasoning and differences in the amount of time spent in procedural rather than problem-focused talk (Higgins, Mercier, Burd & Joyce-Gibbons, 2012). Further studies highlighted the importance of the division of roles and showed different patterns of organisational and intellectual leadership in groups using multi-touch tables (Mercier, Higgins & Da Costa, 2014), the importance of classroom layout for task completion Mercier, Higgins & Joyce-Gibbons, 2014), the differences in teacher decision making process when shifting from group to whole-class dialogue (Joyce-Gibbons, 2016), the development of adaptive expertise among group members (Mercier & Higgins, 2013) and the affordances of the tables to structure representations of reasoning processes (Mercier & Higgins, 2014). The principal limitation of the original *SynergyNet* study was that the research was only ever conducted within the lab-classroom rather than in a real-world school environment. Other previous studies have also been concerned with how the use of multiple large touchscreen interfaces impacts on collaborative education in single environments, i.e. individual classrooms (Basheri & Burd, 2012; Kreitmayer, et al., 2013; Mercier, Vourloumi & Higgins, 2015), instead of adapting to robust teacher and pupil use and dealing with the technical challenges of the school's infrastructure. This is one of the chief priorities of the ongoing research agenda, to test the utility of the tables in authentic classroom settings.

One of the key advantages of collaborative education across multiple locations is that it allows students with a potentially diverse range of knowledge, backgrounds

and skills to work together (Kizilcec, 2013). In this context, the opportunities for educational collaboration across multiple locations afforded by co-located interfaces via large networks, both open and closed, needs to be explored Daradoumis & Marquès, 2000). Such a move would allow users at both locations to collaborate using the touchscreen interface, offering the opportunity for a range of novel gestures to intuitively instigate specific actions which can be beneficial for younger users (Kim et al., 2007). One such gesture is the `flick' motion (Reetz et al., 2006) which is typically used for the movement of materials about an environment with minimal effort. This gesture can aid collaboration, allowing users to transfer materials to each other without needing to enter each other's interaction space. It is possible that the flick gesture could be used, not only for passing content between users on the same interface, but for passing materials to users on remote interfaces.

This work is contextualised by the substantial ongoing reform of ICT education in England and Wales; in particularly, the disaggregation of ICT into computing, IT and digital literacy, as well its intersection with the wider technology-enhanced learning agenda (and related scrutiny on the digital competencies of all teachers). We have thus seen a new computing curriculum established in England from September 2014 (Brown et al., 2014), as well as emerging ICT curriculum reform in Wales (Arthur, Crick & Hayward, 2013). This paper details the innovative technical work undertaken to support a trial that investigated the impact on collaborative interactions of using large touchscreen interfaces in two separate geographic locations, specifically with two classrooms with groups of students aged 7-11 (Key Stage 2 in England and Wales). Furthermore, this paper represents a valuable case study of the technical aspects of implementing a research trial using multi-touch devices, examining how the technology infrastructure was used to collect the wide range of research data, as well as presenting solutions to the key technical challenges faced.

## 2. Meeting the challenges of synchronous remote collaboration

The original SynergyNet studies explored learning by developing tools to be used explicitly in a lab setting where groups of students were co-located and activities

were well supported by team members at hand with technical expertise. This paper relates the technical challenges which the team faced and overcame as they attempted to introduce SynergyNet into multiple classroom settings simultaneously. This study enabled the enhanced use of some features already present in the framework, such as network flick and the mystery tasks used in previous studies. However, it also required some development in other areas to enable the framework to be deployed over the Internet rather than over a local area network (LAN). The section details the key features of this SynergyNet which were already present in the framework in previous studies.

## 2.1 The study set-up

The physical set up of the study involved a single multi-touch table in a quiet room in each location. Each table was a Samsung SUR40, with a rectangular screen mounted on its legs. Three chairs were arranged around one of the two longer edges of the rectangular multi-touch table. A tablet computer was placed perpendicular to the table on the opposite edge, facing the chairs. Figure 1 shows the set up with groups facing each other in each school. A session had a group of three participants working together at a table in each school. They communicated via Skype, run on a tablet computer in front of each group (thus the groups regarded themselves as being opposite each other). In total 24 learners participated in the study, four groups of three children from each school. Each session lasted for approximately 20 minutes.



*Fig1 Groups from School 1 and School 2 facing each other via Skype*

The two schools selected to participate in this study geographically distant schools in the UK (approximately 300 miles apart), one in the north-east of England and

the other in south Wales. Despite their distance, the two schools share a common industrial heritage; specifically, they were located in villages which had prospered when their local economy was based on coalmining. More recently, both areas have experienced significant post-industrial socio-economic trauma with the closure of the mines and de-industrialisation. Both schools were located in similar socio-economic circumstances reflecting this decline. The head teachers of both schools expressed concern that impact on the children living in these former mining communities has led to a dislocation with their environment as they grow up with little or no first-hand knowledge of mining, although are aware of the cultural heritage of the community (as are their families).

## 2.2 The *Mysteries* tasks

The Mystery task selected represented an attempt engage the learners in a collaborative activity which would give them the opportunity to share their understanding of mining and how this related to their own area. They had to investigate involved a 10 year old boy who was injured in a mining accident. Based on the available evidence (presented in text snippets on one of the two multi-touch tables) they were asked to jointly arrive at an explanation of what had actually happened to cause his injuries and then to discuss who was to blame for these (Leat & Higgins, 2002).

This and other *Mysteries* tasks had been used in several previous *SynergyNet* studies (Mercier, Vourloumi & Higgins, 2015; Mercier & Higgins, 2013; Joyce-Gibbons, 2016) where students use a selection of clues, such as snippets of text and images, to solve a problem or come to a conclusion about the open questions as shown in Figure 2.

The *SynergyNet* framework[2] allowed any item in its supported applications to be moved and manipulated by users through common multi-touch gestures, as well as supporting communication between multiple interfaces via a network connection. The framework supports several different methods of transferring

---

[2] Available on GitHub: https://github.com/synergynet

materials between instances of its apps; the use of networked interfaces allowed media-based content to be easily shared between multiple users, allowing both intra- and inter-group collaboration as shown in earlier *SynergyNet* studies (Mercier & Higgins, 2014). `Network Flick' was developed which allowed learners working at each table to flick content, thereby transferring content from one table to another by using a flicking gesture (Reetz et al., 2006). Existing versions of the *Mysteries* task are supported by several apps for the *SynergyNet* framework. The key innovation of this study in the development of the Mysteries tasks is the utilization of the flick gesture in interactions for the first time.
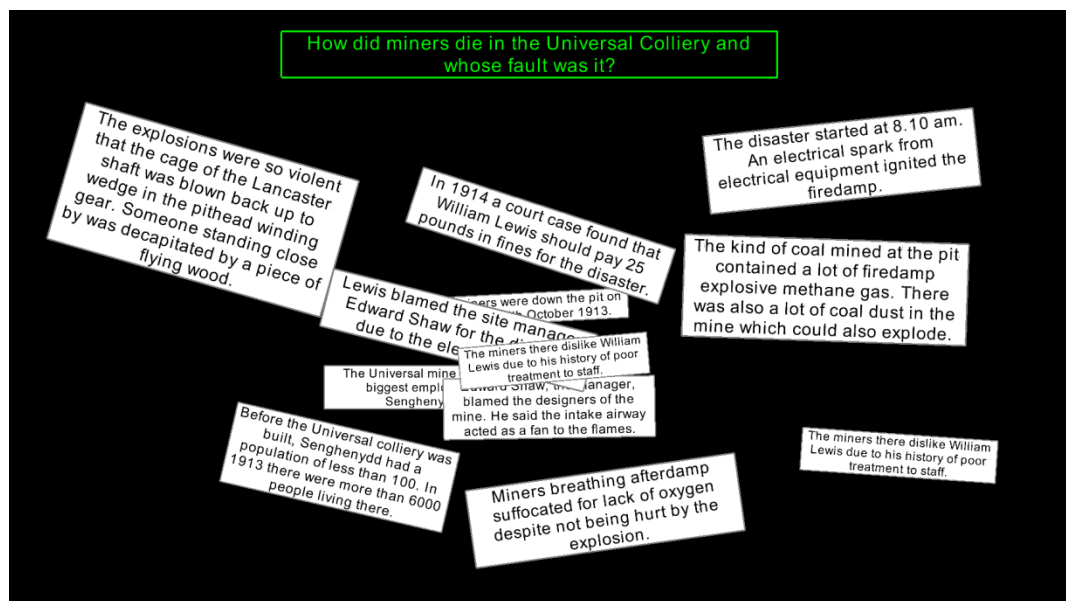


**Fig2** *The SynergyNet Mysteries app with task content used in our trial.*

This required the creation of a new app which would manage the loading of the materials in a dynamic way and allow them to be transferred through the network gesture. Figure 1 shows the app built for the trial with content relevant to the task dynamically-generated from a structured text file (XML format) ready for transfer via the network flick mechanism. This included text snippets from a structured XML file and media from any other files in a folder; although video and audio clips are supported by the app only text snippets were used to reduce potential

confounding factors. The dynamic content system allowed for the app to be easily configured so that each site would have a different selection of clues for each mysteries task, forcing them to share content with the students at the remote location.

2.3 **Network Flick**

The network flick gesture is built upon the physical metaphor of pushing items around on a low-friction surface (such as ice), now regarded as a common feature of many mobile and touchscreen devices (Moyle & Cockburn, 2005). A small amount of initial effort can allow the item on which the force is being exerted to travel a great distance, whereas friction can be applied to decelerate flicked objects over time. This is useful for both helping users keep control of items (for example, so they do not continue to travel indefinitely at high speeds after being flicked, making them difficult to grab and stop) and for making the behaviour of items better match their real-world equivalent, again linking back to the metaphor of sliding objects on ice.

The networking element of this gesture appears when users flick a content item in the direction of the interface to which they wish to send content; the item travels to the side of the initial interface, disappears, and appears on the target interface as shown in Figure 2. Flicking in a direction where there is no connected interface results in the item bouncing to the interface boundary, as would be expected in the real world.

When the item arrives on the target interface, the framework uses its knowledge of the interface locations to ensure the item appears in view from the appropriate direction of the source interface. This aids users in easily identifying from where newly arrived content items have been sent when interfaces are co-located. The use of a flicking gesture not only informs users on recipient interfaces of the origin of transferred items but also creates an intuitive way of sending and sharing content. Users can select their recipient through the direction of the flick and thus initiate the transfer simply by moving the item in that direction and releasing it. This is intended to reduce the cognitive load usually required to move content between interfaces. The potential benefit of this approach, by having a simple

method to move content between interfaces, users will be better able and willing to share items due to smaller barriers to sending and receiving.

Though the network flick gesture has a number of potentially benefits, little use has previously been found for it; the feature was present in the SynergyNet framework since its earliest versions, but very few apps utilise it. While some apps that require the transfer of materials between interfaces do support the gesture, most encourage users to use other, more traditional, methods of sharing contents (such as placing items in shared areas or through using a context menu).
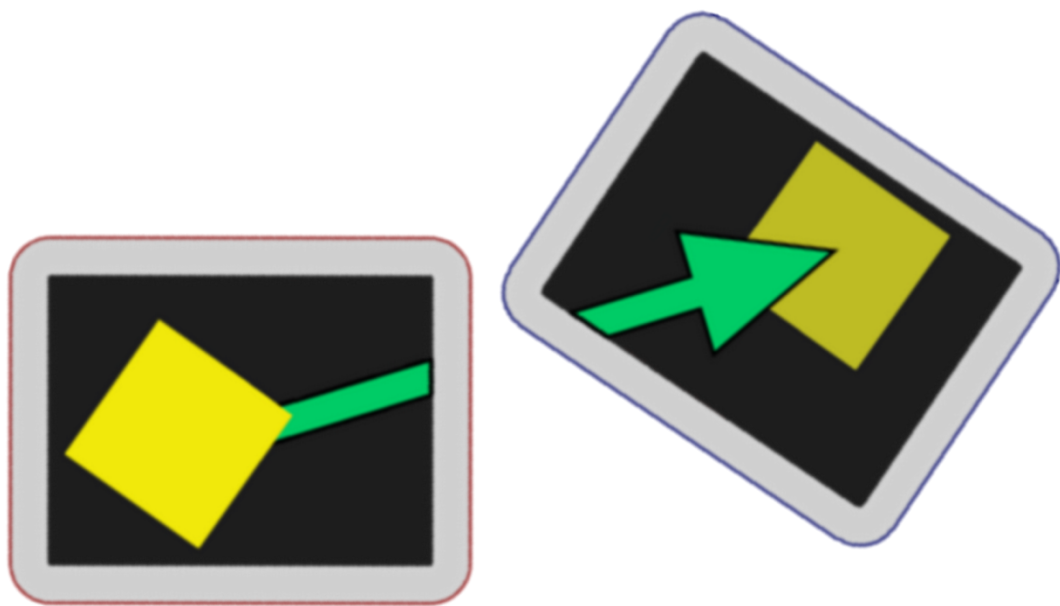


*Fig 3* *The use of the network flick gesture to transfer content between two example co-located interfaces.*

Previous studies have investigated the human-computer interaction aspects of the network flick gesture but none of these have entailed its use in a classroom environment (Coldefy & Picard, 2007). Typically, classroom-based studies with *SynergyNet* have utilised a remote teacher interface to orchestrate the transferral of content (Hatch & McNaughton, 2011). Though the gesture had often used in the warm-up and cool-down sessions (to get participants used to interacting through the touchscreen devices and as a form of play reward) during previous studies with Key Stage 1 (age 5-7 years) and Key Stage 2 (age 7-11 years) students, little data was collected on its use by participants as part of classroom teaching and learning activities.

# 3. Technical Challenges

Having outlined the features of the existing SynergyNet framework which it was possible to adapt to facilitate synchronous remote collaborative learning activities, this section addresses those features which presented a barrier to doing so. Initially SynergyNet was designed for co-located collaboration, incorporating architecture which was not able to support remote working. This section outlines the challenges faced in terms of the framework, the school setting and mobile connectivity.

### 3.1. Co-Location

Although efforts were made to ensure that the SynergyNet framework was as adaptable and extensible as possible, functioning across multiple environments in separate locations was not a priority during its past development. Consequently, several issues in the design of both the framework and the apps became apparent in the current project.

The majority of *SynergyNet* features were developed on the assumption that users would be located in the same physical environment and thus able to see each other's screen directly. This informed the design of visual elements, such as the menus. For example, the menu used by teachers to load and transfer content in previous studies assumed that the teacher was able to see pupil's interfaces, so that they could choose which group's work to display to the class. As this was not the case for this study the in-app menu system was removed to avoid potential disruptions through its use. As content loading was managed through the configuration of the app and transfers instigated through the flick gesture, there was no need for the teacher menu so its removal did not cause any issues.

Furthermore, the network flick gesture itself has an in-built assumption about its use: users will know where their target interface is in relation to them. However, this knowledge can also be made available to users even when their target interface is in a remote location. The implications of not directly seeing the target interface when performing a network flick gesture are the key foci of this new strand of work and will be discussed in terms of the networking challenges, and content transfer behaviour.

### 3.2. Network Challenges

#### 3.2.1. Overview

The use of single environments in the past has meant that the framework was always deployed across a single local area network (LAN) in all studies; therefore, many of the features are not immediately capable of functioning across the wider internet.

Despite the intention of being used solely across LANs in the past, a large amount of the framework's networking capability was built in such a way that it could easily function across the internet. The use of third-party libraries such as OpenFire[3] (a real-time collaboration (RTC) server that uses XMPP/Jabber (the widely-adopted open protocol for instant messaging) and Hazelcast[4] (an open source in-memory data grid for simplified distributed computing, written in Java) mean that the framework can use several different protocols across wider networks for communicating messages to each other.

However, there are some network features that are solely limited to LAN; an example of this is how media content is transferred between instances of the framework. The framework uses a shared network location as a form of cache, which was beneficial in the past as it was simple to implement and gave teachers a single location to collect the files used in a lesson for use in future lessons. The *Mysteries* app only sends data when first discovering other instances of the app and when a content transfer occurs. The first time any content is sent it is moved to the shared area on the network; afterwards, all subsequent transfers point back to the same item in the shared area, treating it like a cache.

The secure use of a shared network location across a wider network, such as the internet, is inadvisable without precautions due to data security and latency of such a technique. It was therefore a requirement that some development work

---

[3] https://www.igniterealtime.org/projects/openfire/

[4] https://hazelcast.org/

took place prior to the trial taking place to allow the framework, or at least the app used, to function over the internet as the two locations used would not be able to share a typical LAN.

### 3.2.2.  Virtual Private Networking

As many of *SynergyNet*'s networking features (including the network flick gesture) are dependent on the devices being on the same local network, when moving to working with different locations and networks there are a number of technical issues to identify and overcome, especially working in educational environments. It became apparent that the most effective approach would be to emulate a LAN across a wider network (i.e. the internet). This solution was decided upon as supporting direct communication across the internet would have required several of the framework's key networking features to be completely re-engineered, which was not feasible in the time-frame of the study,.

The most effective way to emulate a LAN in this type of environment was to utilise a virtual private network (VPN), allowing many of the features of a local network that *SynergyNet* relies on (such as shared folders), whilst still communicating across the wider internet. Though various VPN solutions are available – both free and paid-for services -- Zero-Tier[5] was selected to provide network virtualisation services. This low-cost VPN solution was able to support the necessary networking features over the internet. As only two table-top machines were required to be connected to the same network in the trial (i.e. one touchscreen table-top interface for each site), it was not necessary to use a more feature-rich VPN. The tablets used in the trial for the Skype did not need to be on the same network as the table-top interfaces and could function over the internet. Given the sensitivity of the settings and the participants security of the connection was a major consideration. Although Zero-Tier may not be as provably secure as other VPN options (for example, those that guarantee anonymity with no logging), the trial did not involve any private data being transmitted between the two sites so this was discounted for the trial.

---

[5] https://www.zerotier.com

### 3.2.3 School Security

An unexpected problem was encountered with the use of Zero-Tier on the school networks. It was originally intended that all devices used in the trial could be connected to the internet via the schools' own network infrastructure as both the tablets and table-top interfaces are capable of using wireless connections. However, during preparation for the trial it was discovered that the firewalls at both of the schools were explicitly blocking outbound VPN traffic relating to Zero-Tier. The use of the Zero-Tier VPN had previously been tested in environments with strict firewall policies (e.g. university networks) and had operated as expected; however, it appears that the school firewalls were locked down much more than anticipated, with extremely limited outbound connections allowed through the firewall.

While this has been a known issue in the past, especially due to e-safety concerns and wider protection issues in a school environment, there has been a concerted effort for local education authorities not to indiscriminately "block and lock" networks without justification, especially in Wales (Welsh Government, 2015). This meant that *SynergyNet* could not operate when connected to the Zero-Tier VPN through the schools' networks. Whilst adding exceptions to the firewalls would have allowed the VPN connections to function correctly, this was not feasible due to administrative issues with approval via the school and local education authority; therefore, an alternative method of connecting to the internet was required.

### 3.2.4 Mobile Networking and Connectivity

Due to these permission issues with the schools' own network infrastructure, an alternative method of connecting to the internet that would allow the table-top interfaces to function was identified using pay-as-you go 4G mobile dongles. These could be connected via USB to the two table-tops to allow them to connect to the internet through a relatively fast mobile connection. However, due to the

14

geographical locations of each school, it proved difficult to find acceptable coverage using a single mobile network, so the interfaces at both sites were connected to the internet via two different 4G providers. This had no noticeable impact or latency on the connection and allowed the instances of *SynergyNet* on both table-tops to interact quickly and with minimal data loss (for example, there were no noticeable instances of failed transmissions of messages between the instances would result in flicked items never arriving on their target device).

A 4G mobile connection may not be as secure as using the wired school network. However, data to and from the VPN was end-to-end encrypted ensuring it would be secure; furthermore, task design ensured no sensitive or personal data was transmitted between the tables.

### 3.2.5 Multi-Casting

Prior to the current project, *SynergyNet* had used multicast service discovery as a method of automatically finding other running instances of the framework on a network. However, many VPNs do not support the User Datagram Protocol (UDP) that *SynergyNet* employs. Thus, to accommodate this constraint, the framework was modified to work purely through the more widely supported Transmission Control Protocol (TCP). This change meant that *SynergyNet* could no longer automatically detect other instances using multicast service discovery. Therefore, at least one instance would need to be informed of the IP address of the other instance. To support this new functionality, a user interface was developed which allowed for the user to identify participating device's IPs on the network. This update was initially a change at the app level but has since been integrated into the framework so that all apps on the latest version of *SynergyNet* (Mercier, 2014) can work over VPNs more easily.

### 3.3. Content Transfer Behaviour

The tablet computer showing each group of participants the other group via Skype was placed on the long table edge opposite to them. The tables were configured so that flicking items towards the tablet (and therefore the other group 'facing' them)

would transfer these items to the remote table. This was achieved by configuring the tables so that they were virtually positioned next to each other, with the sides on which the tablets were placed being parallel to each other. This meant each table operated as if the other was co-located with it. With students passing items towards their 'window' to the other team, the metaphor of physically pushing items towards another interfaces was maintained.

Virtually positioning the tables side-by-side also meant that the entire edge of the tables with the tablet on (one of the longer edges of the widescreen aspect ratio interfaces) could be used as the target for network flicks. If the two tables were configured to use their real-life locations in relation to each other, the size of the boundary where a network flick could be trigged (i.e. that points to the remote table) would be less than a pixel at the distance between the two locations.

Another benefit to this configuration of the tables being placed virtually side-to-side relates to behaviour of the transfer. Normally a realistic effect is employed with time taken for items to transfer is calculated by the time it would take from travel the gap between the interfaces at the speed of the item before it left its source interface (ignoring deceleration). This is useful for co-located interfaces as it reinforces the metaphor of real objects being pushed around the environment. Clearly this behaviour would not be suitable with the interfaces using their real-world locations in the trial as it would take a long time (in this study the multi-touch tables were 300 miles apart) even with the fastest flick gesture the interfaces are capable of identifying. Therefore, the virtual distance between the tables was set to be as small as possible. This meant the flick behaviour had the effect of items travelling the shorter virtual distance from one interface to the other when flicked in a direction with a trajectory that would eventually intercept the nearby virtual representation of the remote table..

### 3.4. Limitation: Data Collection

Screen recording software was installed on both tablets allowing both sides of the video conferencing software used for communication between the groups to be recorded. In addition to this, stand-alone cameras were used at both locations to record in high-definition interactions with and around the table-top interfaces.

16

Previous SynergyNet studies have been informed by detailed data collection of touch frequency and location during activities. This data was collected on separate lab-based infrastructure which was not possible to replicate in the current study. *SynergyNet* uses OpenGL (a cross-language, cross-platform API for rendering 2D and 3D vector graphics) for its visual output. Video capture from the table-top screens was problematic because, using a secondary device that mirrored the output of the table would have affected the visual output configuration and impacted on the performance of the device. This in turn would adversely affect the intuitive operation of the tables. This was considered an unnecessary risk to the study for the potential data collected. Future research will explore data capture solutions which do not risk inhibiting the performance of the tables.

## 4. Conclusions

Firstly, the process of preparing, running and collecting data from this project has demonstrated that *SynergyNet* can be used successfully to facilitate collaboration beyond physically co-located groups in a single laboratory setting to collaboration between groups at different locations. In fact, this is the first real-world use of such kit in this type of scenario. The innovations and adaptations described above now allows the framework, and any of the applications it supports, to be used across multiple sites, facilitating further research trials in collaboration between remote sites using natural user interfaces. Furthermore, the project has established that the 'flicking' of content between these geographically remote groups can allow effective and timely sharing of content leading to successful problem solving activities. This was only possible, however, due to the successful adaptation of the *SynergyNet* framework's networking features to work through a VPN.

These innovations have identified and attempted to resolve or mitigate a number of important technical considerations when using the equipment in a real-world school environment, rather than a lab. Many of these technical challenges have been based around networking and connectivity, especially with institutional concerns regarding e-safety and child protection. Team members regularly

informed key stakeholders (in each school these included the Headteacher, the Childre Protection Officer, the class teacher and parents) in the schools of their activities and the steps they were taking to avoid and manage possible risks to participant safety. The use of 3G and 4G mobile network connections to avoid the difficulties of locked-down school networks may prove to be useful in future studies, but this overlooks potential issues around latency and security. In the study described above, no personal or sensitive data was sent through the network connection and all information was encrypted via the virtual private network. However, the use of a secure wired school's network is preferable where feasible, providing improved connectivity and resilience. This may require significant preparation, testing and approval processes before research studies can be conducted in situ.  In addition, although the trial used a set of specific multi-touch table devices, the portability of the *SynergyNet* framework potentially allows for it to be run on a range of different devices. This affords the opportunity to deploy similar trials into a wider range of consumer devices in the future, with little reliance on the bespoke and expensive hardware available.

With the changes to the framework made as part of the trial, *SynergyNet* (and associated pedagogic practices) is now better suited for use across the internet where a VPN is set up appropriately. This allows for the tables used in the trial to be re-deployed anywhere where there is an acceptable 3G/4G signal or with an alternate network connection where the network is configured appropriately.

Finally, this project has shown the potential of the *SynergyNet* software in educational settings, both co-located and at remote locations. It suggests that, despite a number of technical barriers that have had to be overcome, the software framework provides the potential for innovative pedagogic practice and collaboration which would otherwise be impossible with conventional digital devices and associated resources.

# References

Arthur, S., Crick, T., & Hayward, J. (2013). The ICT Steering Group's Report to the Welsh Government.

http://learning.gov.wales/docs/learningwales/publications/131003-ict-steering-group-report-en.pdf. Accessed 8 January 2017.

Barron B., & Darling-Hammond L. (2008) Powerful Learning: Studies Show Deep Understanding Derives from Collaborative Methods. Edutopia http://www.edutopia.org/inquiry-project-learning-research. Accessed 8 January 2017.

Basheri, M., & Burd, L. (2012, October). Exploring the significance of multi-touch tables in enhancing collaborative software design using UML. In: 2012 Frontiers in Education Conference Proceedings (pp. 1-5). IEEE.

Brown, N.C.C., Sentance, S., Crick, T., & Humphreys, S. (2014). Restart: The Resurgence of Computer Science in UK Schools. *ACM Transactions on Computer Science Education,* 14(2), 1-22.

Coldefy, F., & Louis-dit-Picard, S. (2007, June). DigiTable: an interactive multiuser table for collocated and remote collaboration enabling remote gesture visualization. In: 2007 IEEE Conference on Computer Vision and Pattern Recognition (pp. 1-8). IEEE.

Daradoumis, T., & Marquès, J. M. (2000, April). A methodological approach to networked collaborative learning: Design and pedagogy Issues. In: Networked Learning 2000. Proceedings of the 2000 International Conference on Innovative Approaches to Lifelong Learning and Higher Education through the Internet (pp. 72-77).

Dillenbourg P., & Evans M. (2011). Interactive tabletops in education. *International Journal of Computer-Supported Collaborative Learning,* 6(4), 491–514.

Everitt K., Shen C., Ryall K., & Forlines C. (2006) MultiSpace: Enabling Electronic Document Micro-mobility in Table-centric, Multi-device Environments. In: Proceedings of 1st IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TABLETOP'06). IEEE Press.

Hatch A., Higgins S., Joyce-Gibbons A., Mercier E. (2011). NumberNet: Using Multi-touch Technology to Support Within and Between Group Mathematics Learning. In: Proceedings of the 9th International Conference on Computer Supported Collaborative Learning, pp 176–183.

Hatch, A. & McNaughton, J. (2011). "SynergyNet 3.1." https://doi:org/10:5281/zenodo:54562, 2011. Accessed 8 January 2017.

Higgins S., Mercier E., Burd L., & Joyce-Gibbons A. (2012). Multi-touch Tables and Collaborative Learning. *British Journal of Educational Technology,* 43(6), 1041–1054

Joyce-Gibbons, A. (2016). Observe, interact and act: teachers' initiation of mini-plenaries to scaffold small-group collaboration. *Technology, Pedagogy and Education*, 1-18.

Kharrufa A., Balaam M., Heslop P., Leat D., Dolan P., & Olivier P. (2013). Tables in the Wild: Lessons Learned from a Large-scale Multi-tabletop Deployment. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI'13), pp. 1021–1030. ACM.

Kim, J., Park, J., Kim, H., & Lee, C. (2007). HCI (human computer interaction) using multi-touch tabletop display. In: 2007 IEEE Pacific Rim conference on communications, computers and signal processing (pp. 391-394). IEEE.

Kizilcec, R. F. (2013). Collaborative learning in geographically distributed and in-person groups. In: Proceedings of the 16th International Conference on Artificial Intelligence in Education (AIED), pp.67-74. CEUR-WS (vol. 67).

Kreitmayer S., Rogers Y., Laney R., & Peake S. (2013). *UniPad*: Orchestrating Collaborative Activities Through Shared Tablets and an Integrated Wall Display. In: Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'13), pp. 801–810. ACM.

Kyaw, P. & McNaughton, J. (2010). "SynergyView" https://doi:org/10:5281/zenodo:54566. Accessed: 8 January 2017.

Lipponen L., Hakkarainen K., & Paavola S. (2004). Practices and Orientations of CSCL. In: *What We Know About CSCL*, Springer, pp. 31–50.

McConnell, D., Hodgson, V., & Dirckinck-Holmfeld, L. (2012). Networked learning: A brief history and new trends. In: Exploring the theory, pedagogy and practice of networked learning (pp. 3-24). Springer.

Mercier, E. (2014). Device ecologies to support collaborative learning in classrooms. In: 2014 International Conference on Collaboration Technologies and Systems (CTS), (pp. 217-218). IEEE.

Mercier, E. (2016). Teacher orchestration and student learning during mathematics activities in a smart classroom. *International Journal of Smart Technology and Learning*, 1(1), 33-52.

Mercier, E. M., & Higgins, S. E. (2013). Collaborative learning with multi-touch technology: Developing adaptive expertise. *Learning and Instruction*, 25, 13-23.

Mercier, E., & Higgins, S. (2014). Creating joint representations of collaborative problem solving with multi-touch technology. *Journal of Computer Assisted Learning*, 30(6), 497-510.

Mercier, E. M., Higgins, S. E., & Da Costa, L. (2014). Different leaders: Emergent organizational and intellectual leadership in children's collaborative learning groups. *International Journal of Computer-Supported Collaborative Learning*, 9(4), 397-432.

Mercier, E. M., Higgins, S. E., & Joyce-Gibbons, A. (2016). The effects of room design on computer-supported collaborative learning in a multi-touch classroom. *Interactive Learning Environments*, 24(3), 504-522.

Mercier, E., Vourloumi, G., & Higgins, S. (2015). Student interactions and the development of ideas in multi-touch and paper-based collaborative mathematical problem solving. *British Journal of Educational Technology*.

Moyle, M. & Cockburn, A., (2005). A flick in the right direction: a case study of gestural input. *Behaviour & Information Technology, 24*(4), 275-288.

O'Donnell A.M., Hmelo-Silver C.E., & Erkens G. (2013). *Collaborative Learning, Reasoning, and Technology*. Routledge.

Reetz, A., Gutwin, C., Stach, T., Nacenta, M., & Subramanian, S. (2006, June). Superflick: a natural and efficient technique for long-distance object placement on digital tables. In Proceedings of Graphics interface 2006 (pp. 163-170). Canadian Information Processing Society.

Rick, J., Harris, A., Marshall, P., Fleck, R., Yuill, N., & Rogers, Y. (2009). Children designing together on a multi-touch tabletop: an analysis of spatial orientation and user interactions. In Proceedings of the 8th International Conference on Interaction Design and Children (pp. 106-114). ACM.

Stahl G., Koschmann T., & Suthers D. (2014). Computer-supported Collaborative Learning: An Historical Perspective. In: *Cambridge Handbook of the Learning Sciences*, (revised version), pp. 479–500.

Welsh Government (2015). Recommended web filtering standards for schools in Wales. Guidance document no: 169/2015. Welsh Government. http://gov.wales/topics/educationandskills/publications/guidance/web-filtering-standards/?lang=en. Accessed 8 January 2017.

Wu, M., & Balakrishnan, R. (2003). Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In Proceedings of the 16th Annual ACM Symposium on User Interface Software and Technology (pp. 193-202). ACM.