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Collaborating around Digital Tabletops: Children's Physical Strategies from the UK, India and Finland

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We present a study of children collaborating around interactive tabletops in three different countries: the United Kingdom, India and Finland. Our data highlights the key distinctive physical strategies used by children when performing collaborative tasks during this study. Children in the UK tend to prefer static positioning with minimal physical contact and simultaneous object movement. Children in India employed dynamic positioning with frequent physical contact and simultaneous object movement. Children in Finland used a mixture of dynamic and static positioning with minimal physical contact and object movement. Our findings indicate the importance of understanding collaboration strategies and behaviours when designing and deploying interactive tabletops in heterogeneous educational environments. We conclude with a discussion on how designers of tabletops for schools can provide opportunities for children in different countries to define and shape their own collaboration strategies for small group learning that take into account their different classroom practices.

Categories and Subject Descriptors: **H.5.3 [Group and Organisation Interfaces]**: Collaborative Computing, **H1.2 [User/machine systems]:** Human Factors

General Terms: User study, interactive tables

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1. INTRODUCTION

Interactive tabletops in educational settings have been argued to have desirable properties that promote participation and collaboration between students during the learning process (Price et al. 2004; Harris et al. 2009; Jamil et al. 2011; Rick et al. 2011). For example, the students can organise themselves into small groups around digital learning materials on the multi-touch tabletop to facilitate face-to-face discussion (Dillenbourg et al. 2011; Higgins et al. 2011). Collaboration around a digital tabletop has also been shown to support task-based and reflection-type conversations (Harris et al. 2009; Jamil et al. 2011) as well as to foster creativity and engagement (Falcão et al. 2009; Cao et al. 2010). Hence fostering collaboration is desirable since collaborative learning provides an opportunity for children to practice higher level thinking skills (Webb 1982a). In addition, Higgins et al. (Higgins et al. 2011) highlighted that due to the tabletop geometry, it encourages equitable participation among participants (see also findings from (Harris et al. 2009) and (Rogers et al. 2009). Also tabletops' multi-touch features enable simultaneous participation in a collaborative learning environment, allowing parallel individual interactions with the digital content to be made visible, supporting shared awareness, coordination and understanding (Marshall et al. 2008; Harris et al. 2009; Rogers et al. 2009). Such features are desirable in collaborative learning, where problem solving and group coordination are of value (Peterson et al. 1985; Johnson et al. 2009).

Even though most studies of the use of digital tabletops in educational settings have been conducted in the United States (US) and the United Kingdom (UK), reductions in their cost, the growing awareness of their utility, their move out of research laboratories into the classroom (e.g. (Cao et al. 2010), and global economic shifts mean that we are beginning to see their deployment in other countries. However, studies of their use in Austria (Nagel et al. 2009) and Japan (Mori et al. 2010) suggest that tabletop applications that are insensitive to different national settings may not draw out the full value of participants' interactions with them (Hofstede 2001).

This has also been observed in the deployment of other educational technologies, as users choose different kinds of problem-solving approaches, or are influenced by their cultural norms and educational or environmental experiences, making the application less successful (Duveskog et al. 2003; Lund et al. 2004). Deploying the same application in different countries without first understanding its user and environment can also have a negative impact on the user experience (Lund et al. 2004; Chavan 2005; Li et al. 2009; Scissors et al. 2011; Setlock et al. 2011; Reinecke 2012). In one dramatic example of this, I-BLOCKS, an interactive tool for learning programming that was designed in Europe and then deployed in Africa hindered children's learning due to differences in the teaching methodologies between the countries (Lund et al. 2004).

Our understanding of the impact of nationality differences on the usage of an advanced technology like tabletops in educational settings, and the existing literature on the topic are remarkably thin, with the research clearly orientated towards Western users. There is little multi-country data that examines differences or similarities across Western countries given that their educational system is not a uniform one shared by all, and linguistic, cultural, pedagogical and practical differences are likely to impact the practices, relevance and acceptability of digital tabletop systems (Morris et al. 2001). Understanding the interactional behaviour of children collaborating around digital tabletops in different countries is essential to ensure that optimal educational opportunities are open to non-Western users, as well as caring for ethnic minority groups (e.g. Asians, African Americans, etc.) within Western countries, a point of equal access that has social, educational and legal implications. Furthermore, adding comparative data from multiple countries to the corpus of predominantly Western-based tabletop studies provides insights for both the tabletop and education communities.

To this end, we present a study of children engaged in a peer-learning task around interactive tabletops in three different countries: the United Kingdom, India and Finland. Linguistically and geographically, all of these countries are remote from each other, and have distinct social norms. Yet there are shared features of cultural life across them. While participants in India are non-European, India has a long cultural and educational connection with Britain as part of the Commonwealth (Hofstede 2001; Nisbett 2003). As Western nations, Finland and the United Kingdom have a common European location. All participants are likely to be exposed to Western media through the Internet, films, TV and music to various extents.

It is reasonable to expect that many factors could confound an analysis of the results of a comparative study carried out over different countries, such as group dynamics (Rick et al. 2011), group composition (Lee 1993), socio-economic status (Stock et al. 2008), or gender (Inkpen et al. 1997), but to account for all of these factors in a controlled experimental study would require an unfeasibly large amount of data and resources. Instead, the study described in this paper has been designed to minimise the setup differences and maximise the collaborative experience of the children, with similar tabletop configurations, interaction techniques, tasks and teacher-researcher consultation. This research serves as a baseline for any multi-country deployment of digital tabletops.

The focus of this paper is therefore to observe the different layers of physical strategies used when children collaborate around digital tabletops in the UK, India and Finland when presented with an educational-based task. We examine how actions are produced, understood, and made visible in relation to the spatial and material arrangement of peers and tabletop artefacts. We first discuss the relevant literature to ground the paper before presenting our study, results and design guidelines. Our findings showed that children in the UK tend to prefer a fixed positioning with minimal physical contact while children in India displayed dynamic spatial positioning, frequent simultaneous object movement and physical contact as part of their collaborative strategies. Children in Finland displayed a mixture of behaviours between the children in the UK and India, demonstrating both the fixed and dynamic spatial positioning and employing both the simultaneous object movement and physical contact as part of their physical strategies.

2. RELATED WORK

2.1 Collaborative Learning

While the literature on collaborative learning does not yet have consensus agreement on its foundational concerns and theory, at its broadest interpretation, it involves a situation in which two or more people learn or attempt to learn something together (Dillenbourg 1999). There is a considerable body of evidence showing that working together in learning has pedagogical advantages: children learning in groups tend to achieve better academic outcomes compared to other children learning under a whole-class teaching method or under an individual learning scheme (Webb 1982b; Sharan et al. 1988). Moreover, collaborative learners show to be more interactive and active participants, more focused on the task, and use more "sophisticated language strategies" in solving learning problems (Sharan et al. 1988). Students benefit through collaborative work when they participate in discussions, give ideas and provide solutions (Webb 1982c). During the collaborative problem solving process, learning can occur as a side effect as students explore, discuss, reflect and negotiate on the given topic (Barnes et al. 1978) which will likely result in a successful experience (Deutsch 1949). This shows the need to encourage collaborative work during the knowledge building and learning processes.

Given the benefits and importance of collaborative learning, our study uses the digital tabletop technology to support the collaborative learning experience of children in multiple countries. During the activities presented in this paper, the students work in small groups of up to six peers interacting and communicating with each other in order to solve as a group a given task using digital tabletops.

2.2 Interactive Tabletops as Educational Tools

Educational applications of multi-touch tabletops are especially promising as the device's large horizontal surface allows for multiple learners to interact with the digital resources simultaneously. From the HCI perspective, users interact with the digital resources directly with their fingers offering *natural* interaction techniques (i.e. no mediator or additional input device is required) between users and the digital objects. This multi-touch configuration enhanced the learning experience of students by reducing the need to compete for input channels (Harris et al. 2009).

The multi-touch feature is attractive for supporting collaborative learning, and at the same time promotes equitable participation (Higgins et al. 2011). This technology is becoming more affordable driven by the decreasing cost of projection technology, materials and the availability of open source multi-touch operational software. Another feature that the digital tabletop offers is that the technology is designed to support co-located team work- a much desirable feature in the current education system (Dillenbourg et al. 2011). Moreover, its capability to support objects, both digitally and physically as well as its ability to be integrated with other systems like mobile phones during co-located collaboration much contributes towards an enrichment of face-to-face interactions. Hence, there is a growing deployment of this technology in educational institutions such as schools, colleges and universities. The work by (Cao et al. 2010) and (Falcão et al. 2009) further highlights the potential of digital tabletops within educational contexts.

(Higgins et al. 2011) have proposed a typology of the features of digital tabletops that could potentially promote learning and pedagogical benefits:

- *Surface.* The complete horizontal configuration of a digital tabletop is ideal for small group collaboration. The quality of a digital tabletop surface (i.e. screen resolution) is also important as learners need to be able to easily synthesize text and information on the screen (Bernard et al. 2002). A digital tabletop also can be customised such that learners can have both forms of spaces- individual or private working space and a shared group working space for both competitive and collaborative activities during the learning process (Higgins et al. 2011; Klinkhammer et al. 2011).
- *Touch.* Users can directly interact with the digital tabletop using their fingers without the need of external devices- a form of natural interaction. If needed, other types of touch techniques can be incorporated, such as using tangibles (Falcão et al. 2009), or styli (Ha et al. 2006), thus extending the capabilities of this technology to suit various purposes.
- *Connectivity.* Digital tabletops can be connected either locally or remotely. For example, a digital tabletop can be connected to local devices such as a mouse,

keyboard, camera and microphone (such as the TellTable propose by (Cao et al. 2010). It can also be connected to other digital tabletops in a network setting as proposed by (AlAgha et al. 2010).

All users have equitable input contribution i.e. there is no one user who monopolises the input system, hence users have to communicate with each other in order to coordinate themselves to complete the given task (Stewart et al. 1998; Stewart et al. 1999). This is observed in a more recent study carry out by Fleck et al. (2009) during which it was understood that even when students do *physically* block other students actions or monopolise the shared objects in a multi-touch table, the students still have to verbalize and explain their actions, searching for group consensus in order to achieve the group unified goal (Fleck et al. 2009). Hence, conversation and physicality as communication strategies go hand in hand to attain collaboration (Fleck et al. 2009). Since physical actions are such an integral and important part of the use and manipulation of multi-touch interactive systems (Rogers et al. 2009), in our work we pay close attention to the *physical* communication strategies around multi-touch digital tabletops during collaborative processes.

2.3 Tabletop learning activities and applications

The increasing use of tabletops in educational settings has been accompanied to the proliferations of learning activities and applications to use alongside the device. For instance, Evans et al. (Evans et al. 2009; Evans et al. 2011) deployed the SMART Table for children to learn geometry in schools by using both off-the-shelf and custom built applications. Their initial findings showed an "increased in communication and cohesion to higher-level principles" (c.f. (Evans et al. 2011)) for children that worked in the SMART table setting. This shows a promising outcome for communication and collaboration around digital tabletop when children are presented with an educational task.

In another learning activity, children were presented with the Digital Mysteries task (Kharrufa et al. 2010), a collaborative learning activity around a digital tabletop. By collaborating around digital tabletops to solve a mysteries task, children were seen to perform higher level thinking through the process of reflection (Stahl 2006). Mind mapping, spider diagrams and concept mapping are learning activities also widely used in schools. The aim is to externalise knowledge by creating relationships between ideas and synthesise new knowledge from existing concepts (Novak 2008). Maldonado (Maldonado et al. 2010) investigated the usage of Cmate a concept mapping system or spider diagram for education designed for digital tabletop. Their work shows that users find it easy to merge and group similar ideas and categories together in the digital device and that the application facilitates the users' discussion when exploring the topics. Mind mapping helps to facilitate the development of strategies, communication and understanding on a particular concept (Cañas et al. 2008). Similarly, in a relevant work (Jamil et al. 2011) investigated children creating a spider diagram using three conditions- direct touch on digital tabletop, pantograph on digital tabletop and a non-digital tabletop (paper based activity). Their study showed that interactions techniques across those three conditions had an effect to the conversation patterns.

In our work, we built upon the results of (Jamil et al. 2011) and drew from the idea of concept mapping to design, develop and deploy a spider diagram task (similar to the concept mapping by (Do-Lenh et al. 2009) and (Maldonado et al. 2010)) as a digital tabletop application. The application was created in collaboration and consultation with teachers in the three countries of the study to ensure topic and task appropriateness. Participants built spider diagrams based on key topics from their learning development. The spider diagram application used in our work where users group, categorise and organise similar ideas together, relates to concept mapping as described and implemented in the literature (Novak 2008).

2.4 Physical Strategies in Different Cultures

Developing from the issues of internationalising technology across countries and their educational approaches, the learners' cultural and national backgrounds are likely to impact their acceptance of technology for learning. Between countries, the ways that collaboration occurs through educational technology can differ for many reasons, from socio-cultural to the simple act of accessing resources. For example, research shows that when using traditional PCs in rural India in educational settings there is a tendency for group learning to be dominated by the oldest, brightest and richest children (Pawar et al. 2007). Providing shared resources (e.g. through using multiple mice) can facilitate children from mixed backgrounds and abilities working together on interactive educational software (Pawar et al. 2007).

Theorists such as Nisbett (Nisbett 2003) and Hofstede (Hofstede 2001) acknowledge that culture may impact our behaviour through our thinking process, values, habits, societal power, and avoidance of uncertainty, amongst others. In the fields of HCI and Computer-Supported Collaborative Work (CSCW), there is a growing awareness of the impact that culture has in technology usage. (Scissors et al. 2011), for example, demonstrated that American and Japanese users preferred different working styles to each other i.e. individual vs group-oriented behaviour. Also in the educational technology field, for example, Romanian students tend to show a greater gap in gender differentiation (Hofstede 2001) and to be more collectivist and group oriented compared to German students (Weinberger et al. 2010).

Additionally, Marshall et al. (Marshall et al. 2009) reported a study of children in the United Kingdom using a digital tabletop and a non-digital tabletop to help organize a seating position for their classroom. They reported that children in the digital tabletop condition tend to use their hands to cover the digital objects and at times pushed other children's hands as part of their collaborative strategies. Potentially this notion leads us to speculate the kind of behaviour that we may observe when children interact around digital tabletop.

In an interesting application of context-sensitive technology deployment, children that have had a long history of national hostility were seen creating a narration task using digital tabletops (Stock et al. 2008). The narration task was used as a tool to mitigate conflict: children had to agree on what items (picture, video and audio) to include in their storyline before they could add more items. This allowed children to discuss and negotiate their ideas, and also to express themselves in order to come to a consensus. This highlights the importance of understanding the user's background and behaviour and then using those elements in creating clever interaction techniques or application features to foster healthy collaborative experiences.

These studies suggest that for interactive systems to be deployed in different settings, they need to be attuned to the environment, nationalities and cultural sensitivities of the users so as to maximise their effectiveness (Hofstede 2001; Nisbett 2003; Reinecke et al. 2011), making the notion of "one-size-fits-all" an unsuccessful methodology when deploying applications (Rick et al. 2011). This is not a unique observation: the Finnish researchers (Lund et al. 2004) in their work contrasted the "learning by heart" method that children in Africa are exposed to with the Western system of knowledge (creative thinking when solving problems, or quantification inference, see for e.g. (D'Ambrosio 1999) that children in Europe are typically familiar with. The contrast showed how a teaching technology developed in Europe was not fully compatible with the ways that children in Africa were accustomed to learning, prompting difficulties with technology acceptance.

In our study we examine video recording of learning encounters in the three countries of deployment in order to understand the different physical strategies used in context when children interact around a digital tabletop. This knowledge is desirable to ensure the proper acceptance of the technology within its environment. Such findings also offer a useful lens through which to explore the success of the technology across multiple countries.

3. STUDY DESCRIPTION

3.1 Participants

We recruited participants from student groups that were of similar ages and composition across the three countries. We allowed for some flexibility in terms of group assignments in each country so as to account for organisational practicalities within the different institutions. Moreover, we wanted to reflect the real-world scenario- that is, in some schools children tend to self-select their members whilst in other schools groups tend to be assigned by the teachers. It would be impractical not to consider and allow for both aspects to occur as it is not a true reflection of the classroom settings. We did not observe any interactional difference across the age groups (as participants were grouped with similar age students) and group assignments that would impact the children's collaboration around digital tabletop. We describe these participant groups and the study conditions below for the countries that the study took place in. Participants worked in small groups between two to six students which is in line with the small group criteria (Barnes et al. 1978; Hirokawa et al. 2007).

3.1.1 India

139 pupils aged between 11 and 13 years old (110 females and 29 males) were recruited from two schools in Delhi. The study lasted for three days at both schools. Participants were divided into 27 groups of 4 to 6 pupils, a typical size for group-based classroom activities in these schools.

For anonymity, we identify these as 'School A' (fee-paying school) and 'School B' (government-funded community school). All pupils had access to PCs, and were familiar with concepts in interactive computing to varying extents, although with a greater exposure at School A. The medium of education in both schools was English, although students in School A spoke English for the entire study, while in School B, they preferred to talk in Hindi. The video recordings for School B were therefore translated and transcribed prior to analysis.

In School A, the assignment to groups was performed in consultation with the teachers to create groups of compatible ability levels. All pupils within the groups were known to each other, being from the same class and familiar with working together in group-learning activities. Groups in School B were self-selecting and consisted of children from the same class who were familiar with working together on group learning tasks. Groups were free to choose when to attend sessions during school hours.

3.1.2 United Kingdom

30 pupils aged between 11 and 13 years old were recruited (16 males and 14 females) from 2 schools in Bristol and the study lasted for two days. Participants were divided into 8 groups consisting of between 2 and 4 pupils. Their assignment to groups was performed in consultation with the teachers to create groups of compatible ability levels. All pupils within the groups were known to each other, being from the same class and familiar with working together in group-learning activities.

3.1.3 Finland

78 pupils aged between 11 and 15 years old were recruited (18 males and 60 females) from schools in the North Karelian region. The study lasted for three and a half days. Participants were divided into 22 groups of 2-6 pupils; all groups were self-selected and consisted of children from the same class and who were familiar with working together on group tasks. The tasks were explained to the students in English however they preferred to speak Finnish among themselves. The video recordings were transcribed and translated prior to analysis. Although children varied between 11 and 15 years of age, they were grouped with children of the similar age group or class levels to ensure subject-knowledge compatibility.

3.2 Apparatus

Four rear-projected multi-touch digital tabletops based on the FTIR configuration (Han 2005) were used, one in the UK, two in India, and one in Finland. Tabletop configurations varied slightly due to the local availability of materials for building each device but care was taken to minimise the technological difference: 1) UK: 102cm x 101cm and 76cm high with a projection of 72cm x 48cm 2) India: 90cm x 90cm and 76cm high with a projection of 72cm x 48cm and 3) Finland: 104cm x 58cm x 87cm high with a projection of 98cm x 56cm. The task applications were created using Adobe Flash and Action Script 3. The tables were located at schools (India), a HCI lab (UK), and at a public science fair arena (Finland). Though ideally the tables should be deployed at similar locations but due to pragmatics this was not possible. As mentioned, the setup, technology and tasks were similar in all of the three countries for consistency purposes.

3.3 Tasks and Techniques

The aim of this study was to observe the physical strategies and interactions that occur around digital tabletops when the device is used as an emerging educational tool in different countries, hence we employed digital media for the design, development and deployment of the educational task. The use of digital media in a tabletop is further justified by the results of (Rogers et al. 2009). In their study, (Rogers et al. 2009) looked at group participation using three conditions: laptop, digital tabletop with tangibles and digital tabletop without tangibles. Their results showed that the digital tabletop without tangibles produced the most equitable participation through physical actions, which is what we aim to observe.

Additionally, most if not all of the digital tabletops in the market use the direct touch technique as the de facto standard for users' interactions. On the basis that direct touch is an acceptable universal interaction technique, and that it promotes desirable utterances for collaborative learning and equitable participation through physical actions (Jamil et al. 2011), we chose this technique as baseline for comparing the children's interactions around digital tabletops in the India, UK and Finland.

Based on our consultation with teachers in multiple countries, they agreed that spider diagrams are a common teaching tool in classroom to help students externalize existing knowledge and promote better understanding on a particular topic. In a study, researchers explored how multimodal spider diagram and technology can enhance the teaching and learning experience in a classroom (Cuthell et al. 2008). Their study highlighted that using a teaching tool such as a spider diagram with technology has a significant impact on the learning environment, on pupil perceptions of learning, and on attainment. Thus for the task, all students worked on a collaborative learning activity that involved building a spider diagram on a digital tabletop: similar to creating a 'mind map' in which a topic is investigated and explored by visualising associations and relationships between key concepts. Using this learning task design we seek to foster the externalisation of knowledge (Novak 2008) through collaborative work around the tabletop in order to fulfil the learning task objective as a group.

We presented the children with an ecologically appropriate topic that tallied with what they were learning in the classroom. All topics were based on the National Curriculum from each country and were developed in close collaboration with teachers from the respective countries to ensure appropriateness. Each country therefore had a different topic suited to the educational experience of the participants at school for their age groups and current classroom activities: Photosynthesis (Figure 1, left), Energy and Food Chains (Figure 1, centre), and Sustainable Energy (Figure 1, right). Although the topics were tailored to the local requirements, there was no difference in the learning activity that was involved (i.e. building a spider diagram) and how the content was presented or the enabled interactivity of the digital tabletop. Keywords of the topics were placed at each of the four sides of the table, oriented towards the participants on that side of the table. Another set of keywords were positioned around the table, scattered around the main topic image. These keywords included a combination of words and images to stimulate the conversation. This layout is similar to the work done by Jamil et al. (Jamil et al. 2011).

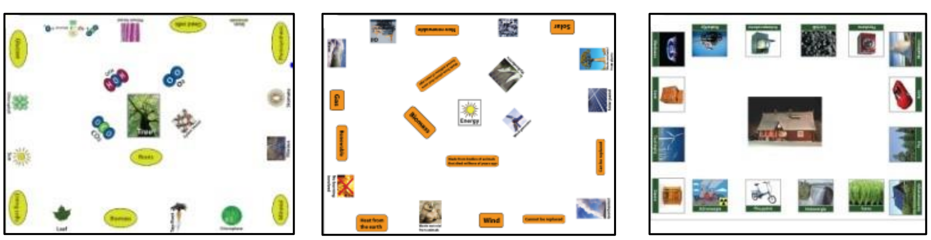


Figure 1. Photosynthesis in India (left), Energy in UK (centre), Sustainable Energy in Finland (right)

The outlined layout of content on the tabletops can be seen in Figure 1; students were able to move, scale and rotate objects, to cluster them as well as to draw and delete lines between or around items on-screen. The children in the three countries took an average of 15 minutes to complete the given task. This reflects the time allocated in the classroom for this type of activity.

3.4 Data Collection and Analysis

During the sessions, students were exposed to the interaction techniques and learning activities and the tasks were explained to them. The groups were given 15 minutes on average across the three countries to familiarise themselves with the task and the tabletop interface. Nevertheless, majority of the students were familiar with touch technology due to the usage of touch-based devices (e.g. mobile phones, iPads, etc.). As a consequence, the students were rapidly acquainted with the tabletop technology and were at ease with the task and interaction technique. Participants were told to take as much time a necessary to complete the activities and learning explorations. Video was used to record the physical and verbal behaviour of all the groups performing the activities. These recordings would be the basis of subsequent analysis. Once a group had completed their task, an experimenter conducted a debriefing interview with the group to explore their experience with the different activities and the tabletop to compliment the video based data.

As the study was conducted in real-world settings, we have been able to explore naturally occurring behaviours that took place as a result of the children's collaboration. Several real-world studies also follow this approach e.g. (Marshall et al. 2011) and (Hinrichs et al. 2011). Our analysis draws on an iterative and detailed examination of the video recordings and focuses on the interactional behaviour of children when completing the given task (Jordan et al. 1995). Following (Marshall et al. 2009), the analysis was developed through repeated observation of all the video data to select sequences of interest. These sequences were then transcribed, viewed several times and discussed with other researchers in the project to unfold the interactions that occurred in further details.

We articulate the interaction details of how gestures, talk and action are produced, coordinated, made visible and understood with respect to the table and on-screen objects, following the methodology of the existing literature on interaction analysis (Jordan et al. 1995). We also extracted sequences of video frames or vignettes depicting the children's interaction with digital objects. For anonymity, the names of the participating students have been changed and their faces blurred; they are labelled as Pn (e.g. P3) in the images and transcripts to identify individuals. Some of the images have been enhanced (contrast and brightness) to highlight particular interactions in those vignettes.

Scholars have yet to come to an agreement as to the 'best' worldview approach for a study such as ours, as it depends on the research questions, problem areas and so forth. In our work, the one that fits closely (although it is not restricted to) is the pragmatism worldview. Many contemporaries such as Murphy (1990) and Cherryholmes (1992) and historical figures such as Charles Sanders Peirce and John Dewey embraced this idea (Creswell et al. 2011). The pragmatism worldview tend to "draw on many ideas, using diverse approaches and valuing both objective and subjective knowledge" c.f. Cresswell and Plano Clark (Creswell et al. 2011) p.43. This is a useful perspective for analysing the rich video data of our study.

We applied qualitative content analysis through video observations to explore the interactions that took place during collaboration around digital tabletops. Content analysis was useful as we did not have preconceived categories or fixed variables beforehand (Stemler 2001) but instead we wanted to explore and understand from the data itself the underpinning interactions of the children during their collaboration. We also applied descriptive statistics through frequencies and percentages to summarise the data (Thompson 2009). Following these methods allowed us to show *richness* in the data- presenting aspects such as the physical strategies (spatial positioning, simultaneous object movement and physical contact) by using observations and transcriptions of the children's conversations and behaviours.

Our analysis approach is also in line with the analysis performed by prominent tabletop researchers that have investigated the physical and behavioural strategies when participants collaborate around digital tabletops such as Rogers et al. (Rogers et al. 2004), Marshall et al. (Marshall et al. 2009) and Rick et al. (Rick et al. 2011). Our analysis allowed us to look at the collected rich data holistically- to understand collaboration not only from the low level interaction aspects (i.e. frequencies of occurrences) but also from the perspective of social dynamics and interactional context such as physical strategies. Following this, our paper adopts an approach where we place a greater emphasis on the qualitative methods (Creswell et al. 2011) and the statistical methods have a supporting role. We believe that this is the best approach for drawing out a rich context of physical strategies around digital tabletops from our data.

4. RESULTS

The findings reported here demonstrate how children in India, United Kingdom and Finland employed physical strategies during group work in classrooms while using interactive digital tabletops. The most prominent strategies observed were *spatial positioning*, *simultaneous object movement* and *physical contact*. Spatial positioning refers to the physical displacement of the children *around* the tabletop; simultaneous object movement occurs when more than one child manipulates the same digital object *on* the tabletop at the same time; physical contact involves direct contact with other children *above* the tabletop, for example pushing another child's hand away or hitting another child's hand.

During the analysis, the video data was repeatedly viewed and sequences of the physical behaviour strategies were selected. These sequences were further analysed, transcribed and viewed several times to understand how children use spatial positioning, simultaneous object movement and physical contact while collaborating around digital tabletop. Table I illustrates these strategies quantitatively, showing the overall frequency of observed behaviours by country alongside the average number of times the behaviour was performed per participant. The results highlight that children in India displayed the most in terms of all the observed physical strategies. Children in the UK exhibited static positioning with some occurrences of simultaneous object movement and physical contact. Meanwhile children in Finland displayed greater spatial positioning than in the UK with some occurrences of simultaneous object movement and physical contact.

Physical Behaviours	India	UK	Finland
Spatial Positioning	459	19	63
Average per participant	*3.30*	*0.63*	*0.84*
Simultaneous Object Movement	432	73	82
Average per participant	*3.10*	*2.43*	*1.09*
Physical Contact	526	35	22
Average per participant	*3.78*	*1.17*	*0.29*

Table 1. Behavioural distribution for children collaborating around the digital tabletop by country. The numbers indicate the observed behaviour frequency and mean participant behaviour per country.

4.1 Spatial Positioning

Our data shows that spatial repositioning was used as a practical strategy for organising learners' interactions, as children moved from one location to another around the digital tabletop. However, there appear to be differences across the three settings observed. There is much more instrumental movement by children in India throughout the learning task. Subtler spatial movements were also seen with the children in the UK, although they were not seen to move to different positions as a means of reconfiguring the interaction (as seen with the other national groups) but rather, stood up or sat down, and tilted their bodies towards the objects of interest. Meanwhile, children in Finland exhibited a mixture of dynamic and fixed positioning around the tabletop. In our analysis, a total of 541 instances of spatial positioning were observed distributed in the three countries of the study, see Table 1.

4.1.1 India

Children in India exhibited fluid and dynamic spatial positioning around the tabletop (in average a child repositioned 3.3 times during a session). In general, we saw that children did not attach themselves, or stay at one location; rather they moved fluidly around the tabletop (see Figure 2). In the example below, five children from School A in India were discussing photosynthesis when the following interaction occurred:

```
P1: "Look this is the entire process of photosynthesis! All of these go here! This is photosynthesis!"
```

P1 pointed to a group of keywords (O2, CO2, Phloem, Photosynthesis) using both of his index fingers (Figure 2a). He then swung both of his hands to the left side of the table to another set of keywords (Mineral, Sun and a few other non-visible keywords) whilst looking at P2 and P3.

Figure 2. (a). Initial positioning; P1 points to keywords with right and left index fingers. (b) P1 and P3 shifting positions. (c) P1 and P4 shift positions; P4 assisting P1 with a keyword.

```
P5: "Oh my God! You're smart! We need to move everything there!"
P1: "Just move all these here"
```

P2, P3 and P5 then move several keywords (not-visible) from the left to the right side of the tabletop.

P1: "CO_2 is here, here!"

P1 then moved to the other side of the tabletop, swapping positions with P3 (Figure 2b). P1 pointed using his index finger to Glucose (somewhere in the middle of the side of the tabletop where he was standing) and then moved his hand and pointed towards CO_2 at the corner of the tabletop, before saying:

P1: "P4, CO_2 is here!"

P1 pointed towards CO_2 at the corner of the tabletop. P4 then tilted her head towards the orientation of Glucose:

`P4: "Yeah you can connect that to that!"`

At this point, P4 pointed to Glucose and CO_2, and P1 then moved Glucose halfway to the corner of the tabletop and took a step back. While watching Glucose being moved, P4 moved from her position towards P1's location, at which point, P1 took a step back. P4 then slipped in front of P1 and touched Glucose using her right hand, to move it closer to CO_2 (Figure 2c).

Noticeably, three out of the five children in this group moved from one location to another at least once in the space of less than a minute. The children's conversation and behaviour provide us with some clues in speculating on the purpose of their movements. First, we see P1 swapping position with P3, perhaps to access an object in that location. This was followed by P4 shifting closer to P1 to assist him with a keyword whilst P1 stepped back to give P4 some space to perform. What we see here is that the children spatially relocate themselves around the distributed digital materials (i.e. the keywords for the Photosynthesis spider diagram), rather than the reposition this content in order to coordinate task completion. In addition to this, they also reposition themselves in order to assist other members. Their conversation clearly orients to the places on the table as being stable ("move everything there", "move all these here"), and the ongoing work of creating complex physical groupings of keywords of on the surface itself make this a reasonable behavioural choice.

4.1.2 United Kingdom

We have no videoed instances in which children physically reposition themselves around the table in the same way as in India. However, we do have examples of more micro-scalar repositioning, as observed in the 19 instances of this behaviour in the 8 groups that participated from the UK. In the example below, a group of two children were discussing several of the keywords that build up 'Energy' around a digital table. The episode begins as P1 stands up and points to three objects one after another in a downward diagonal line (Figure 3a):

a) b)

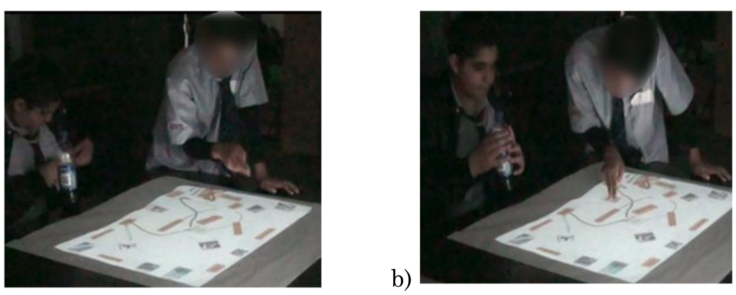


Figure 3. (a) P1 points to an object. (b) P1 shifts slightly to his right as he looks at other objects on the tabletop

At the end of the line, he observably notices an object on the surface, shifts himself towards the corner of the tabletop, then touches and moves the object towards himself (Figure 3b). At this point, P1 bends down to make the object bigger, lifts his fingers, examines the object and scales it back down before drawing a line connecting that object with another object. What we observe here then, is how connections between the objects on the tabletop are made through, and are linked by, embodied interactions: P1's movement of the object directly follows and extends his pointing gesture into a reaching action. As he does so, his body shifts and he is able to take a closer look at the object, appearing to use this focused detail in creating a connection between that object and another object. Although the movement seen here is minimal, this bodily positioning nevertheless appears important in creating relationships between these three objects.

4.1.3 Finland

In Finland, we observed a wide range of granularity in spatial displacement, from large (as seen in India) to subtler movements (as in the UK). 6 of the 22 participating groups displayed large spatial repositioning, whereas this behaviour was subtler in another 8 groups of participants. It is interesting to note that the size of the groups displaying spatial displacement varied. For instance among the 6 groups with large spatial repositioning 3 groups had 3 participants each, 2 groups had 2 and 1 group had 4. In the following vignette of a three participant group, P1 and P2 are becoming familiar with the tabletop and the task (Figure 4a). The sequence began as P1 and P2 were moving icons independently of each other in silence; we then see P1 move to the other side of the table in front of P2 and look at the icons and the application from that side (Figure 4b). This is a slightly odd and unexpected thing to do, as objects and words that would have been (reasonably) correctly oriented towards her would now be upside down.

a) b) c)

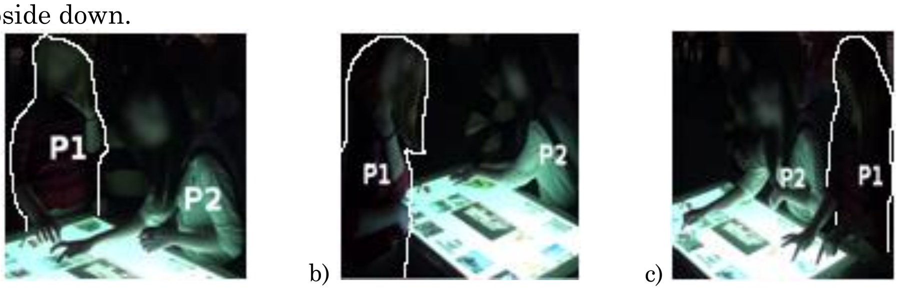


Figure 4. (a) P1's initial position. (b) P1 repositions to stand *opposite* P2. (c) P1 shifting position to stand n*ext* to P2.

After a short while they talk:

`P2 said: "Wouldn't the washing machine..."`

P2 reaches for the icon and moves it. Meanwhile, P1 walks around the other side of the table to stand behind P2.

`P1: "Wouldn't this, P2?"`

At this point, P1 zooms in/out the windmill icon (Figure 4c):

`P1: "Windmill... somewhere."`

While manipulating some other icons, P2 replies:

`P2: "Well, yeah... [and after a pause] Wind. It is energy."`

P1 moves the icon to the centre of the tabletop, speaking:

`P1: "Energy. Yeah, OK then."`

It is noticeable during this dialogue that the utterances referencing objects were delivered alongside pointing ('indexical') actions and spatial displacements instead of verbal explanations of their relationships. As in other cases, here we see how spatial displacements allowed the participants to physically and visually access the icons onscreen without interfering with the visual access and actions of others, allowing all participants direct engagement with the task.

Observations across the three countries indicate that, when used, spatial positioning and displacement around the tabletop allowed the children to access resources more flexibly. Children did not need to rely either on others to do the interactive work on the tabletop for them, or to intrude into or across the areas that other people were working in. They were also able to make their intentions and solutions more visible to others by standing near material they wanted to work on, and making their actions visible to others. Of special interest is the observation that the other members of the group did not seem to be distracted and continued working on the task despite the movement from their peers. The tabletop geometry appears to provide a more suitable learning space than the fixed keyboard and mouse settings of the traditional PC format.

4.2 Simultaneous Object Movement

Multi-touch tables support more than one user touching and moving the same object simultaneously, and we observed many instances of this, in a variety of forms and for different purposes. A total of 587 instances across the countries of the study were recorded (see Table 1). The interaction of moving the same object simultaneously is curious given that for any of the instances observed, any one child could have moved these objects independently. As with the spatial positioning, this behaviour was most prominent in India and to a lesser extent, in the UK and Finland.

4.2.1 India

Previous work has shown that simultaneous interaction with digital objects on tabletops is an integral part of collaboration for children in India (Jamil et al. 2010). In our study observations, on average a child displayed this behaviour 3.1 times during a session. In the example below, five children from one of the groups in School B, India are trying to organise the relationship between tap roots and fibrous roots (Figure 5a). The interaction starts with P2 who was trying to create relationships between tap root (represented by a carrot) and other surrounding keywords (such as sun, fibrous roots, etc.) when she suddenly made the object much bigger, filling the screen (Figure 5b).

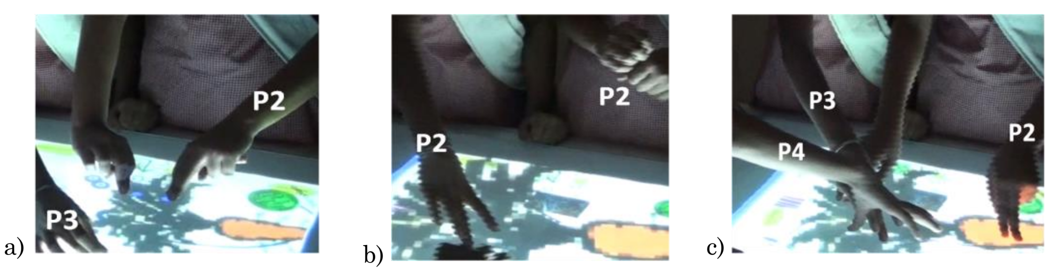


Figure 5. (a) P2 accidentally made *Carrot* bigger. (b) Showing the oversized image. (c) Multi-user simultaneously rescaling.

```
P4: Make it smaller, make it smaller!
```

Almost instantaneously, three children (P2, P3 and P4) touch and scale down the *carrot* (Figure 5c) before carrying on with their activities. This collective rescaling takes place without appearing to show any conflict in their actions. Although P4 calls out to make the object smaller, we can see from the utterance and her gaze that she did not specifically direct it to any of the members. After the object has been scaled down, the children quickly went back to working on the task. It is curious that no obvious verbal or non-verbal invitation led to the children touching or moving an object together, and it is also interesting that there was no verbal dispute, before, during or after the rescaling between the children.

We speculate that the children understood that this was a necessary action to accomplish the group's objectives, and its unproblematic achievement meant that there was no need to formally orchestrate the action as a multiple-user interaction. As with spatial positioning, the horizontal multi-touch feature of the tabletop played an important role in enabling multi-user collaboration, providing democratic access to the interactional resources.

4.2.2 United Kingdom

Although we observed less instances of simultaneous object movement in the UK (only 2.4 times per child in average among the 8 groups of participants) compared to the children in India, we noticed these instances when children wanted to demonstrate understanding, participation and assisting other members. For example, in Figure 6 a group of four children were discussing the connection between *Heat* and *Energy*:

`P1: "Heat from the Earth with Energy!"`

P1 pointed to an object at the top left hand corner of the tabletop and traced a path towards the centre of the tabletop where Energy was located; see Figure 6a).

a) b)

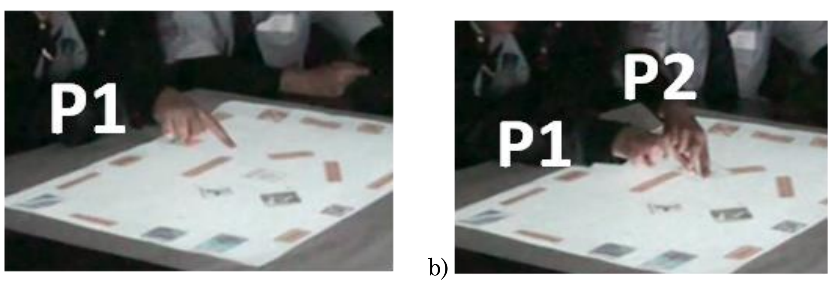


Figure 6. (a) P2 tries to move an object unsuccessfully while P1 points to an object on the tabletop (b) P1 and P2 moving the same object together towards the centre of the tabletop.

In a point and trace action, P1 creates a conceptual path between those two keywords. As P1 makes this tracing gesture, P2 leaned closer towards P1 and followed this path with his eyes:

`P2: "Heat from the Earth, yeah!"`

P2 then dragged *Energy* from the centre of the tabletop towards the corner of the tabletop. As he was dragging it, P1 interjected:

`P1: "Stop, leave it there!"`

As he did so, P1 touched the same object that P2 was touching and both children simultaneously dragged it back towards the centre (Figure 6b). We can speculate from this that P2 agrees to some degree with P1's utterance and action of retaining Energy at the centre of the table, and thus supports this with the co-action of moving it back together with P1. The data shows no sign of disagreement, either verbally or physically between the two members. The simultaneous object movement is thus likely to be a demonstration of consensus by P2 to show his agreement.

4.2.3 Finland

A similar case of simultaneous movement of objects during collaboration was also observed in Finland. This happened when one of the group members was unable to successfully manipulate an object, prompting others in the group to assist them. In the following scenario, the five participant group is discussing how to heat a house, in which P2 tries to move the geothermal heating icon but was unsuccessful in her attempt (Figure 7a).

a)

b)

Figure 7. (a) P2 unsuccessfully tries to move an object. (b) P1 assists P2 to move the digital object together.

This failure occurred because P2 was trying to move the object too quickly and the digital object did not properly 'stick' to her finger. The group noticed this:

```
P3:"as soon as you get it from there!"
```

All members laugh at the interaction and at the same time P1 assists P2 in moving the icon (Figure 7b)

```
P4: "What if we just do like that, that we will draw an arrow from here"
[P4 draws an arrow on the table from the icon to the house]
```

With P1's help, P2 moves the icon near the house, prompting:

```
P2: "now it came"
```

Despite no verbal indication from P2 requiring assistance, P1 offered assistance in moving the object. This assistance appears to be tacitly accepted by P2, i.e. there is no verbal or physical sign of rejection. Hence, this simultaneous object movement is implicitly accepted in order to provide a swift way of fulfilling the goals of the group. We observed this behaviour about once per child in average, among the participating groups.

4.3 Physical Contact

In our observations, children in India exhibited physical contact more frequently compared to the children in the UK and Finland. A total of 526 instances of this behaviour were observed in India alone out of a total of 583 observed overall in the 3 countries, with an average per participant of 3.78 in India, 1.17 in the UK and 0.29 in Finland (see Table 1). Below we describe how children used physical contact as part of their collaboration strategies working with each other in these three countries.

4.3.1 India

A group of five children in School A, India are discussing about *roots* and its associated keywords:

```
P4: “Isn’t roots with stem?”
P5: “No, they are not connected”
```

During this conversation, P3 is drawing circles between two keywords. P4 looks in the direction of P3’s area on the tabletop:

```
P3: “Oh my God!”
P5: “What are you doing?” [P5 stretches her hand above the tabletop with her palm pointed towards P3].
```

P3 continues to draw circles, moving from his area and heading towards the centre of the tabletop.

```
P4: “Stop it!”
```

a)

b)

Figure 8. (a) P4 hitting P3’s hand. (b) P4 pushing P3’s hand away from the tabletop.

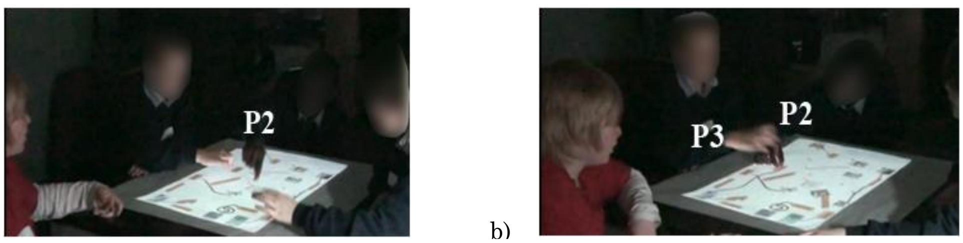
As he says this, P4 hits P3’s hand (Figure 8a) and then pushes it away from the tabletop (Figure 8b). P4 then deletes the circles. P3 stops drawing other circles. The children then continue their discussion about Roots.

In doing this action, P4 provides a physical sanction (hit) to P3 and then prevents them from drawing something that does not contribute towards the ongoing Roots discussion. Interestingly, this physical action follows what appears to be a verbal request by P5 to P3 to stop their action: this reprimanding physical contact therefore does not initiate the exchange, although it was enacted by a different person. We saw frequent instances of such physical gestures occurring in all groups.

This physical contact by P4 here appears to be deployed as a means of drawing P3’s attention to stop his actions (of drawing circles) as well as bringing the group back to the current discussion regarding Roots. Physical contact seems to be an effective way of reinforcing (or indeed, enforcing) verbal commands or controlling an interactional resource. The act of physical contact regularly exhibited among all groups' members in India was more than just blocking access to a digital object (Marshall et al. 2009) or taking control away from another child (Olson et al. 2011). Instead we see the children use physical contact to: 1) get attention from another member, and 2) 'correct' another member's action deemed to be wrong or inappropriate in some way.

4.3.2 United Kingdom

In the following vignette, four members from a group in the UK are creating relationships between two keywords related to Energy. The sequence begins as P2 points to the object that P3 is moving:



a) b)

Figure 9. (a) P2 points to an object of the tabletop. (b) P3 grabs P2's hand and pushes it away from the object.

```
P3: "This one is [with] that!" – [points to another object across the tabletop (Figure 9. (a) P2 points to an object of the tabletop. (b) P3 grabs P2's hand and pushes it away from the object.]
```

Following this, P2 pulls his hand towards his body and rests his palm at the corner of the tabletop. P3 draws a line from that object towards another object. P2 then looks up at P3.

```
P3: "Are you sure?" — [then looks at the object]
P3: "Because it is…" [P2 then stretches his hand and touches the object.]
P3: "No, leave it!"
```

P3 then grabs P2's hand and pushes it away from the object (Figure 9b). P2 and P3 then continue working with other keywords. Here we see that P3 has created a connection between two objects. P2 appears unsure if it was a correct connection, suggesting another object to P3. When P2 touched the object – reasonably, this can be understood as a suggestion to move and regroup the object differently – his hand was physically removed by P3 to stop P2 from changing P3's structure. In doing this action, P3 makes it abundantly clear that P2 was to leave this structure alone. Perhaps P3 considers their decision to be correct; whatever the case, he evidently wants P2 to leave this untouched.

What we see here is very different from the Indian example in which a majority view is enforced through physical contact, and only after this is made visible through talk. In the UK scenario, there is no majority view to shape the interaction as legitimate; and while it is also the culmination of a verbal exchange, the sanctioned actions of P2 prior to the contact are purposeful with respect to the task, and are not visibly or socially agreed upon to be inappropriate. This would therefore seem to be a somewhat coercive physical interaction stemming from an imbalance of power (e.g. of knowledge or strength) between P3 and P2. The final outcome of the interaction is that a grouping is achieved, but one that occurs under duress; in this case, physical contact is used strategically, but not necessarily for the collective benefit for the learner group. This type of instance was noticed about once per child on average among the participating groups.

4.3.3 Finland

In Finland, children used physical contact while interacting around the digital tabletop only in few occasions. When observed, physical contact was used as a playful display or as a way to stop one of the group members from undoing the arrangement that had already been placed in the application. The following example illustrates this as a group of three participants decide how to power an electric bicycle. P1 initially suggests powering the bicycle with nuclear power, and P2 then verbally suggests a seemingly equally ridiculous solution:

```
P2: “Hey, shall we put windmill to the electric bicycle?” – [points at the windmill icon and moves his hand as if he is about to drag it]
P1: “Do not!” — [P1 pushes P2's hand away (Figure 10)]
P2: “Okay, I won't” — [P2 removes hand from the icon]
```

Figure 10. P1 pushing P2’s hand away.

However seldom used in Finland, physical contact appears to serve the purpose of maintaining onscreen arrangement whereas in the UK, physical contact may seem as a coercive strategy to impose a child’s view according to the few instances observed overall there. It is to notice, nevertheless, that physical contact is a rare practice in both Finland and the UK. On the other hand, in India physical contact appears to be used as a way of attracting the attention of the peers, as a non-verbal channel to emphasise opinions and verbal utterances and as a strategy to reinforce the group’s decision, as it was observed in every participating group.

5. DISCUSSION

5.1 Dimensions of Physical Strategies

Our findings point towards various physical strategies for social co-ordination being used when children in multiple countries interact around the digital tabletop to solve their group tasks. Physical interactions were observed across three different dimensions around the tabletop: 1) spatial positioning *around* the tabletop to orchestrate interaction with artefacts and resources, 2) simultaneous object movement when dealing with digital content *on* the tabletop, and 3) physical contact *above* the digital tabletop as a means of directing attention, controlling and sanctioning interaction. Figure 11 highlights the physical strategies patterns across the three countries as a three dimensional space. In our study, the children in India tended to dominate the display of physical strategies while children in the UK and Finland tended to have somewhat similar types of behaviours though they slightly differ in terms of spatial positioning. Many factors such as culture, exposure to technology, education system, relationships, emotions and activities could potentially influence these behaviours (Hall 1968). Our work is framed only in the observations of the behaviours in order to report on the existent physical strategies employed by the participants when collaborating around a digital tabletop.

Our results show that although there appear to be slight variations in terms of the intensity of the spatial (re)positioning *around* the tabletop, children in all three countries practiced this behaviour. While children in the UK tended to prefer fixed, individual positions around the tabletop, children in India, and to a lesser degree, Finland, displayed much more fluid and dynamic spatial positioning throughout the task. In terms of simultaneous object movement *on* the tabletop and physical contact acts *above* the tabletop space (e.g., multiple hitting, pushing and grabbing of other children's hands) children in India also demonstrated more instances of these behaviours than the children in the UK and Finland combined.

In general, simultaneous object movements were employed to potentially enhance collaboration by demonstrating awareness, participation and consensus towards the group and towards the children comprehension of the task. This is in keeping with the results of the study in the wild by Hinrichs et al. (Hinrichs et al. 2011) conducted at a public aquarium in Canada. They found that multi-touch gestures were used to perform a group task collaboratively by several participants manipulating the same single item at once on a tabletop display. In such collaborative explorations children and adults alike were seen using gestures that served the group (e.g., using finger tips to manipulate items instead of the entire hand). Our findings extend this notion by observing the children's collaborative behaviour not only *on* the tabletop but also *around* and *above* it through spatial positioning and physical contact strategies.

Furthermore, although physical contact could be considered as perhaps socially problematic, it can also be a strategy employed to achieve a particular goal, such as protecting digital objects from being accessed by other children as observed by Marshall et al. (Marshall et al. 2009). While some incidents have been mentioned by Marshall et al. (Marshall et al. 2009) and Olson et al. (Olson et al. 2011), there is, however, very little literature available that discusses the social effects and meanings that physical contacts might have during collaboration around digital tabletops. In our study, physical contact supported the collaborative process around the tabletop by stopping members from distracting and subsequently directing the attention of the group away from the particular task at hand. Hence, we observed this particular physical strategy employed to redirect the focus of the group as part of the problem solving process.

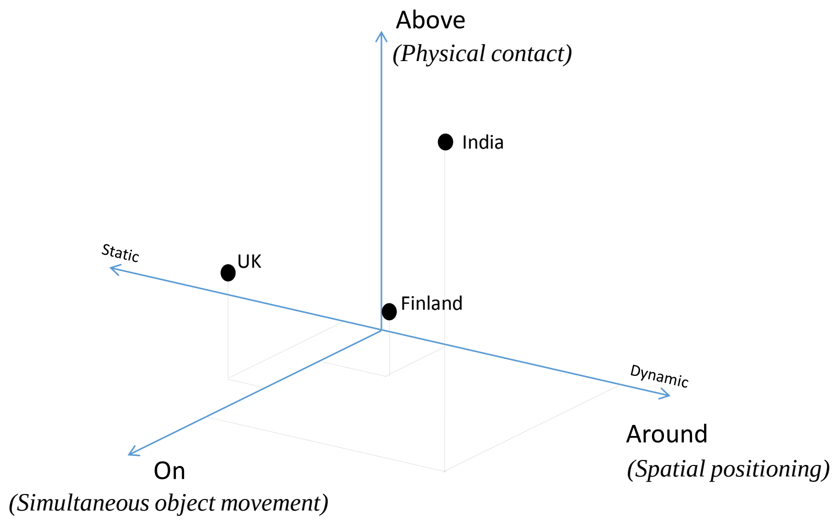


Figure 11. Three dimensional behavioural space based on the observed behaviour frequencies: On, Above and Around the tabletop representing the physical strategies patterns employed by children when collaborating around the device in India, UK and Finland

Based on our observations we speculate that the large display of physical contact of the children in India might be due to the greater role that this strategy appears to play there for gaining attention, and for enforcing collective decision-making. While too much physical contact may hinder collaboration (Olson et al. 2011), for the children in India it seems that physical contact is a natural and somewhat expected behaviour that is part of their collaboration strategy. In the UK, however, physical contact appeared as a coercive strategy, an unexpected behaviour that was used without regard to collective decision-making, which may account for its low prevalence: this behaviour may encounter sanction. In Finland, on the other hand, there was no display of power-play or attention seeking through physical contact but it served as a strategy to maintain the onscreen arrangements of the task.

Bodily actions such as spatial positioning and physical contacts are important aspects during the learning process (Jokela et al. 2013). Broaders et al. (Broaders et al. 2007) have highlighted that making children use their bodily actions, such as gestures, tends to bring out implicit knowledge and this then leads to learning. Similarly, gesturing makes the information gained through the learning process last longer (Maldonado et al. 2010). This resonates with the display of simultaneous object movements that demonstrates how the group members organise themselves to accomplish the task at hand and help express consensus around someone's solutions. Our findings also reflect on learning theories, particularly the constructivism and social constructivism theories, both of which support the idea that students learn when they interact with their environment in building new knowledge through accommodation and assimilation (Balint 1954; Cuthell et al. 2008; Wallace et al. 2008). These theories encourage and facilitate students to explore and discover the learning themselves. Knowledge is then developed when students begin to analyse, synthesise and solve the given problems in a collaborative manner (Sharan et al. 1988). Social constructivism also encourages learners to explore and discover their learning (i.e. learning by doing) (Hofstede 2011), and the tabletop interactions that we see in our data appear to offer good support for this. Based on our analysis, Table

2 describes the observed reasons behind the physical strategies that occurred in all of the three countries.

Behaviour	Observed reasons for employing a behaviour during collaboration
Spatial Positioning	1) Organise learners' interactions and understanding of particular topic of discussion (UK | India) 2) Assist another member as part of demonstrating group cohesiveness, while on the other hand they were aware that the object does not belong to them (India | Finland) 3) Manipulate multiple objects into meaningful spatial relations with each other to represent conceptual relationships (India | UK) 4) Allow the participants to physically and visually access the icons onscreen without interfering with the visual access and actions of others, allowing all participants direct engagement with the task (India | Finland) 5) Make their intentions and solutions more visible to others by standing near material they wanted to work on, and making their actions visible to other (India | Finland)
Simultaneous Object Movement	1) Help other members to manipulate digital objects that may distract and interrupt the group's progress (for example children accidentally resizing a digital object such that it covered most part of the tabletop). By offering assistance distractions are minimised (India | Finland) 2) Help other members who are having difficulty in moving a digital object. By offering assistance, children are able to co-manipulate objects to create relationships across groupings, to build understanding of the topic (Finland | UK | India) 3) Organise themselves to accomplish the task at hand and help express consensus around someone's solutions (UK | India)
Physical Contact	1) Get the attention from another member either to help out with something, or to focus their attention on a particular object on the tabletop (India) 2) Enforce compliance with decisions taken or to correct another member's action deemed to be wrong or inappropriate in some way (UK | India | Finland) 3) Prevent group members from doing off-task activities on the tabletop and to re-focus their attention back to the task so that all of the group members can contribute towards the discussion (Finland | India)

Table 2. Observed reasons for employing the spatial positioning, simultaneous object movement and physical contact behaviours when children collaborated around digital tabletop in India, UK, and Finland.

5.2 Proximity and Space Perception

People that work together tend to maintain close social proximity to each other in their standing and seating position based on a study in the Western world (Hall 1968). Hence, it is reasonable to speculate that the participants in our study would employ the spatial positioning, simultaneous object movement and physical contact to potentially maintain a close social proximity in their working relationship with each other. For example students physically re-locate themselves and move the same object together to help other students and to make their intentions more visible (Table 2). The physical strategies observed could also be an indication to strengthen successful social relationship as they move closer towards each other and/or towards the desired object.

Balint (Balint 1954) proposes two different perceptual worlds: touch- and sight-oriented. Perhaps the touch orientated space is viewed by the participants in India as the friendliest and most immediate space as they are seen to exhibit the most physical strategies compared to the participants in other countries. However, participants in all the three countries demonstrated such behaviours which indicate a presence of a touch orientated space but with different levels of friendliness scale. It is possible in maintaining a sense of social proximity, there is also an element of touch-orientated space that indicates a friendliness and immediate space and interaction between participants. Furthermore, according to Hall (Hall 1968) in social situations the space can be divided into four categories with particular activities and relationship development associated with each: *Intimate*- the presence of a person is very close with possible physical contact; *Personal*- one and a half to four feet where one can hold or grasp another person; *Social*- four to seven feet where impersonal business occur at this distance; and *Public*- twelve to twenty five feet and is associated to a "public figure" distance.

Our observations show that participants in our study tended to operate somewhat between the 'Intimate' and 'Social' spaces during the tasks. For example, participants in India inclined to relocate themselves dynamically to be close to an object or to be close to another participant, frequently employed physical contact with other participants and simultaneously moved an object together. In this 'Intimate' to 'Personal' space, participants may view themselves to be closely and somewhat personally related to each other as to display such behaviours. Presumably, a close sense of social proximity and relationships as well as a high sense of friendliness may be present during the interaction to allow such behaviours to unfold. Participants in the UK carried out their activities in the 'Social' space whereby they tended to operate in a fixed spatial positioning by maintaining a distance between each other. Consequently, this social distance presents a behaviour that may depict less friendly interactions between participants: the participants in the UK had a lower average per person of physical contact and simultaneous object movement compared to the children in India, and the lowest spatial positioning observed in the three countries. Students in Finland, meanwhile, tended to potentially operate between the 'Personal' and 'Social' spaces, where they are seen to dynamically relocate themselves, but employing physical contact and simultaneous object movement less frequently than in the UK and India.

In a study that observed interactions between people at a hospital cafeteria, it was shown that participants that sit adjacent to each other (side by side and corner to corner) had 36% more interactions compared to a face-to-face or distant seating position (Sommer 1959). This aligns with the findings that people are more likely to interact and communicate more with their immediate neighbours (Festinger et al. 1950). This is somewhat noticed also in the physical strategies when children collaborate around digital tabletops in the UK and Finland. That is, simultaneous object movement and physical contacts are likely to happen more between neighbours, which explains the static spatial positioning and minimal simultaneous object movement demonstrated. However, we observed an expansion of this notion with the students in India. Adjacent interactions there are extended from side-by-side and corner-to-corner positions to distant participants situated in various locations of the digital tabletop as they work together to complete the task. We are aware that technological and geographical factors may potentially influence this outcome but it is worth noting that when children in multiple countries collaborate around digital tabletop, it is possible that the notion of interaction between adjacent neighbours maybe extended to other distant neighbours. It is possible that distant neighbours can be considered as adjacent neighbours during collaboration.

It has been stated that classroom (or physical space) configurations may have an effect on task-based conversations and interactions, though no significant difference was reported on off-task conversations between traditional and centred multi-touch classroom configurations (Mercier et al. 2016). Due to the complexity of our study across multiple organisations, countries and physical contexts, it was impossible for us to stick to a particular physical space configuration or student orientation. Instead, in our student-led study participants could perceive or experience some form of ‘freedom’ to exhibit a behaviour that was necessary or instinctive to them during collaboration.

The level of collaboration during a task may also influence the spatial arrangements around the tabletop (in the context of seating positions see for example (Wallace et al. 2008). People tend to place themselves in adjacent positions during cooperative activities while people tend to sit on opposite sides of the table when they are competing with each other (Sommer 1969; Scott et al. 2003). Perhaps the simultaneous object movement and spatial positioning observed in our study indicate the level of cooperation required or experienced during the task. It is possible that due to the strong need of cooperation present, participants tended to move the objects together and also relocated themselves either closer to another participant or closer to a particular object to help take particular actions to achieve their objectives.

5.3 Culture

Balint (Balint 1954) proposes that different people from different cultures tend to navigate space and orientate differently. Though the participants collaborate around the digital tabletop using the same tasks in all of the countries, their interpretations of proximity and space interaction are different which could be due to their respective cultures. For example, in India children move dynamically around the digital tabletop, in the UK they preferred a fixed positioning while in Finland it is a mixture of dynamic and fixed. However, participants in all of the three countries tended to demonstrate some form of spatial movement though some more apparent than others.

Hofstede’s (Hofstede 2001) Individualist Index Values (IDV) may give us some insight into the children’s behaviour when collaborating around the tabletop. Hofstede’s IDV scores were calculated through analysis of adult's responses (Hofstede 2011). Nevertheless, since culture is seen as socially learnt knowledge (Laland et al. 2000), values and behaviours (Hofstede 2001) transmitted among individuals (Laland et al. 2000) it is reasonable to expect that the behaviour displayed by the children in our study is *culturally influenced* because they are individuals growing up within that particular cultural environment (Super et al. 1997). Furthermore, because children are also part of the society they acquire the “societal, national and gender cultures … from their earliest youth” (Hofstede 2011) hence we work under the assumption that Hofstede’s IDV scores apply to them as well.

The smaller the IDV number, the more the participants will perceive themselves as part of a group (collectivist), and the higher the IDV number the more the participants will perceive themselves as individuals (individualist). UK’s IDV is 89, Finland’s is 63 and India’s is 48 according to Hofstede. Hence, we speculate that children in the UK may view themselves more as individuals and pursue individual goals compare with children in India (Scott et al. 2004). This suggests that in the UK physical intrusions on the person’s space or their things are likely to be viewed with suspicion. Meanwhile Finland’s IDV score sits between the UK and India, and we speculate that children in Finland may display a combination of physical strategies because of this orientation.

India is often described as having a collectivist culture (Chavan 2005), and its low IDV score reflects more of a sense of group belonging than the UK or Finland. Our data also suggests that this is the case, making apparent the “everywhere is communal” notion that prevails in India. Hence in the tabletop there is no space or object restriction and children feel that they can move freely around the device or interact without restraint with any object onscreen. As highlighted by Nisbett (Nisbett 2003), Asians are thought to take a more holistic perspective ('paying more attention to the world'), so manipulating objects together might be an indication that they are aware of what each other is doing. Indian children may also feel more comfortable with physical contact if their communal orientation supersedes any objections to personal intrusion.

Another possible explanation for the children's behaviours observed in the UK is the notion that people there tend to have minimal *propinquity* or *closeness* with each other (Hall 1968). Though neighbours living next door to each other, this does not necessarily entitle them to visit, socialise or borrow something – it is a non-contact culture[1]. Presumably, children around the digital tabletop perceive themselves as neighbours and could potentially employ this notion of minimal propinquity. Similarly, Finland has also been categorised as a non-contact culture where interpersonal distance is large and hence any type of physical contact is minimal. Speculatively, children in India, a contact culture, may experience a higher form of propinquity as they allow their neighbours i.e. children sitting next to them, to dynamically move around the tabletop as they work through the task. The frequent simultaneous object movement observed as well as the constant physical contact may also indicate a sense of propinquity or closeness between neighbours or participants. Following this, they prefer to work in a collective manner as they progressively contribute towards the success of the task.

Digital tabletops due to their large horizontal interactive surface have the tendency to promote group awareness where participants are attentive of each other's intentions and actions, as well as exposing mistakes of others, and in some situations inviting criticism from others (Huang et al. 2007). The physical strategies observed could possibly surface from this attribute: in the presence of group awareness participants are encouraged to help each other and perhaps correct others' mistakes (Table 2). In some cultures, it may be socially acceptable to repeatedly correct other's mistakes in a group environment. For instance, a participant is seen repeatedly hitting another participant as he/she is about to perform actions that are not aligned with the group's decisions. However, in some cultures, also potentially due to the group awareness, physical contact is kept to a minimum as it maybe something that is not socially acceptable within that context (Wallace et al. 2008).

Though there are various reasons explaining the spatial positioning, simultaneous object movement and physical contact behaviours, it is important to note that they all serve as an important collaborative learning strategy in helping children to coordinate, negotiate and orchestrate their task during collaboration around digital tabletops.

6. DESIGN GUIDELINES

Based on our findings, we present in Table 3 design guidelines for technologists and educationists for developing interactive tabletop applications, as well as guidelines for multi-national tabletop application deployment. These guidelines serve as a foundation for understanding and addressing the physical strategies during collaboration around digital tabletops.

[1] In a *non-contact culture* "people tend to stand farther apart when conversing, maintain less eye contact, and touch less often", whereas in a *contact culture* "people stand closer together while talking, engage in more direct eye contact, use face-to-face body orientations more often while talking, touch more frequently, and speak in louder voices." (Martin et al. 2010, p 274; see also Hall, 1968)

Expert Aspect	Technology designer/Educator	Multi-national Researcher
Physical Strategies' Dimensions	*Suitability and practicality of tasks* Designers and instructors should consider developing the kind of tasks that can enhance the children's collaboration experience in terms of interaction with the objects *on* the tabletop and with each other *above* the tabletop. Tasks such as spider diagrams, concept maps and so forth were found to be suitable choices.	*Task deployment and comparability* Technology, application type, tasks, interaction techniques, experimental procedure before, during and after the studies, etc., should be replicable as much as possible. This will create common points across the research and allow for easier comparison between collaboration strategies in different countries.
	Tabletop physical layout Given the observed importance of spatial positioning as a collaboration strategy, designers should consider the use of circular tabletops or non-restricting location bound mechanisms to facilitate free movement *around* the tabletop.	
Proximity & Space	*Social Proximity* Participants could employ particular physical strategies to strengthen the success of the social relationship and collaboration by moving closer towards each other and/or towards the desired object(s). Designers and educationists may want to consider particular interaction methods that will either maintain, strengthen or weaken this aspect depending on the task goals. *Level of Cooperation* Participants tend to move from their positions as well as moving an object together potentially when there is a higher demand for cooperation. Designers may not want to restrict the spatial positioning as well as the simultaneous object movement of participants particularly with tasks that require a high level of cooperation.	*Neighbouring Interactions* We saw an expansion of this notion particularly from the students in India and from some students in Finland. Adjacent interactions were extended from side-by-side and corner-to-corner positions to distant participants situated in various locations of the digital tabletop as they work together to complete the task. Researchers may want to be aware of this behaviour and how it may impact collaboration when deploying technologies particularly in *contact* societies. *Interaction techniques* The designed interaction techniques (direct touch, swipe, grab and drop, resize, shrink, etc.) should portray a balanced between location dependent and location independent interactions as children may exhibit and prefer different behaviours.
Culture	*Collective decision making and actions* In order to take advantage of the inherent digital tabletop characteristics that foster collaboration, it is worth considering that in collectivist cultures such as India the group attitude to organising the accomplishment of tasks is of value to children when working around this technology. Conversely, children in individualistic cultures such as the UK tend to display individualistic decision making process. Designers may want to fine tune particular tasks and interaction techniques to suit such needs that is balancing between individualist *vs* group decision making. *Navigation of space and orientation* The interpretations of proximity and space interaction were different between participants in the countries of the study, which might be due to their respective	*Proxemics* The notions of *personal space* and *interaction distance* should be taken into account, for instance, to arrange the spatial distribution of objects on the tabletop. This could avoid certain instances of territorialism in the form of pushing, blocking access and hand grabbing. *Customisation* The cultural backgrounds and geographical locations of multiple users should be taken into account when deploying an application to several countries. Personalisation and customisation are an essential factor in ensuring that learning activities applications are not only well-received but also highly beneficial to local users.

Expert / Aspect	Technology designer/Educator	Multi-national Researcher
Culture (continued)	cultures. For participants from *contact* cultures, allow for frequent dynamic spatial positioning, simultaneous object movement and physical contact behaviours compared to the participants from *non-contact* cultures. *Propinquity* Participants in the UK showed minimal propinquity or closeness, leading to a static positioning and minimal physical contact with other participants. Participants in India showed higher propinquity that invited dynamic positioning and frequent physical contact. Designers may want to consider interaction methods and tasks that will allow for higher propinquity demonstration for participants in India and may expect lower propinquity demonstration in the UK.	*Flexibility* When working with multi-national settings several elements come into play such as languages, protocols, organisational hierarchy, bureaucracy, environment, culture and many others. It is advisable that researchers follow appropriate procedure and allow for some flexibility to suit the local protocols and elements. *Iterative/participatory process.* The involvement of local informants in co-creating learning applications is important in order to ensure the success and functionality of the application. The application design should be an iterative process involving the collaboration of technologist and educationist to create appropriate and practical activities for the students.

Table 3. Design guidelines for technologist, educator and multi-national researcher from the perspective of the physical strategies dimensions, proximity and space perception and culture standpoints

7. CONCLUSION

This paper presented our findings regarding the physical strategies that children in the UK, India and Finland employ when collaborating around multi-touch digital tabletops. Through a close qualitative and empirical investigation of behaviour, we found that children in the UK tend to stay at the same location throughout the task solving process, displayed subtle body movements, and use minimal physical contact with peers when collaborating around the tabletop. Children in India, on the other hand, fluidly reposition themselves around the tabletop throughout the task, frequently moved the same object together, and make regular physical contacts with other members. Meanwhile children in Finland display a combination of fixed and dynamic positioning around the digital tabletop during collaboration, with occasional behaviour of simultaneous object movement and physical contact with one another.

The contributions of this paper are highlighted by: first, presenting the physical interactional strategies of how children in the three countries (UK, India and Finland) collaborate around the tabletop; and second, proposing a set of guidelines for designers when deploying tabletop applications to be used by children in multiple countries. Our findings showed the importance of understanding the cultural settings and the audience so that technological deployment can have a positive impact. We demonstrated that children exhibited beneficial collaborative physical strategies and that the digital tabletop is a useful technology to be deployed in classrooms in multiple countries.

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Closely related prior papers:

- Jamil, I., O'Hara, K., Perry, M., Karnik, A., Marshall, M., Jha, S., Gupta, S. and Subramanian, S. 2013. Dynamic Spatial Positioning: Physical Collaboration around Interactive Table by Children in India. In Human-Computer Interaction – INTERACT 2013, P. KOTZÉ, G. MARSDEN, G. LINDGAARD, J. WESSON and M. WINCKLER Eds. Springer Berlin Heidelberg, 141-158.
- Jamil, I., Perry, M., O'Hara, K., Karnik, A., Marshall, M. T., Jha, S., Gupta, S. and Subramanian, S. Group interaction on interactive multi-touch tables by children in India. In Proceedings of the 11th International Conference on Interaction Design and Children, ACM, (2012), 224-227
- Jamil, I., K. O'Hara, M. Perry, A. Karnik and S. Subramanian (2011). The Effects of Interaction Techniques on Talk Patterns in Collaborative Peer Learning around Interactive Tables. Proc. of CHI, ACM: 3043-30

Each of the papers above highlights only *one aspect of the children's behavior* and are tied *only to one country*. For example our papers on:

- "Dynamic Spatial Positioning: Physical Collaboration around Interactive Table by Children in India" focuses on the dynamic spatial positioning of the children in India when they collaborate around digital tabletop.
- "Group interaction on interactive multi-touch tables by children in India" focuses on the simulataneous object interaction of the children in India when they collaborate around digital tabletop.
- "The Effects of Interaction Techniques on Talk Patterns in Collaborative Peer Learning around Interactive Tables" investigates the talk patterns of the children in the UK when they collaborate across three different conditions- direct touch on the digital tabletop, pantograph on the digital tabletop and non-digital tabletop.

DOI:http://dx.doi.org/10.1145/0000000.0000000

This current paper shows three types of prominent behaviours (two are an extension of the papers above and one is a new findings). Additionally, this paper combines the findings between three countries- the UK, India and Finland prompting awareness for the research community to understand behaviours in a multi-country settings.

B. PREVIOUS SUBMISSION

An older version of this paper was submitted to the IDC 2013 Conference. The reviewers highlighted the following areas:

- Sufficient references to indicate the growing awareness of HCI in culture
- Detailed background study
- Illustrations of data that are easier to understand and decode

The paper has been extensively iterated over the last few years. The above areas have been further addressed. Moreover the authors have included additional key areas to strengthen the paper such as:

- Expansion of the Related Work section include aspects from Collaborative Learning (2.1), Interactive Tabletops as Educational Tools (2.2), Tabletop Learning Activities and Applications (2.3) and Physical Strategies in Different Cultures (2.4)
- Expansion of the Discussion section include aspects from Dimension of Physical Strategies (5.1), Proximity and Space (5.2) and Culture (5.3)
- Added the distribution of behaviours, reasons for employing such behaviours and a three dimensional space that collocate the findings from the three countries
- Expanded the Design Guidelines section to further reflect our real-world findings