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Multi-touch tables and collaborative learning

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Abstract
The development of multi-touch tables, an emerging technology for classroom learning, offers valuable opportunities to explore how its features can be designed to support effective collaboration in schools. In this study, small groups of 10- to 11-year-old children undertook a history task where they had to connect various pieces of information about a mining accident to reach a consensus about who had been responsible. Their interaction using traditional resources was compared with their interaction when using a multi-touch table. Analysis suggests that the design and capabilities of the multi-touch technology offers some key features that supported the collaboration and interaction of the participants, particularly in the early stages of the task. Some of these features appear to provide new opportunities for collaboration and interaction, which were different from the interactions observed in the paper-based groups. These features of the multi-touch surface therefore appear to support effective interaction between the pupils.

Introduction

Large multi-touch surfaces offer opportunities to explore how they can support collaboration and learning. The technology enables several people to control and interact with the information on the same screen, simultaneously (Shen *et al*, 2009). This opportunity for joint control, rather than the single point of control provided by a mouse or single touch screen, is clearly suited to collaboration around the table surface (see Higgins, Mercier, Burd & Hatch, 2011). It provides new opportunities to explore how learners collaborate during educational tasks in a digital environment. In this paper, we explore differences in interactions between groups working on a multi-touch table and groups working on a paper-based version of the same task. This was intentionally an attempt to "computerise a hitherto pencil-and-paper activity" (Noss, Healy & Hoyles, 1997) and an explicit stage in our programme of research. We particularly wanted to explore how the multi-touch compared with similar paper-based activities as a starting point to develop more pedagogically effective activities with more complex resources and interactions. However, as a new educational technology, understanding how learners use the multi-touch environment was limited, so it was important to establish a baseline with activities comparable with those in traditional classrooms. This is to enable successful integration of these technologies

Practitioner Notes

What is already known about this topic

- Research suggests that collaborative interaction supports learning.
- Features such as the nature of the task and the social interaction influence these outcomes.

What this paper adds

- This paper looks specifically at the possibilities when a large multi-touch table is used to support collaboration.
- It compares paper-based and multi-touch versions of the same activity involving school pupils.

Implications for practice and/or policy

- Multi-touch surfaces can support collaborative interaction.
- The initial stages of the task were significantly different.
- Pupils should be encouraged to reach a consensus about what they have to do and how they are going to do it as well as encouraged to produce a joint solution.

into classroom settings and detailed attention to the "orchestration" of learning in such contexts in the future (Dillenbourg & Jermann, 2010).

Collaborative interaction and learning

Effective collaborative learning has long been of interest in education (O'Donnell, 2006) and computer-supported collaborative learning in particular (Dillenbourg, Baker, Blaye & O'Malley, 1996). In this context, the metaphor of group cognition is a key issue in understanding learning in groups (Barron, 2003; Stahl, 2009; Webb & Palincsar, 1996). The development of group cognition is usually seen as a process of articulating, negotiating and coordinating the different views of members of a group. In our work, we draw on the Repertoires of Collaborative Practices Framework (Barron *et al*, 2009), which recognises four overlapping planes of analysis when considering collaboration. This focuses on the importance of each *individual* in negotiating *interactions with peers* and about *the problem* in order to create a *shared representation* and understanding of the task. We also recognise that this collaboration needs to take place in a constructive or "exploratory" (Wegerif, Mercer & Dawes, 1999) social environment where learners are actively seeking a mutual solution to the learning task or challenge (O'Donnell & O'Kelly, 1994). If these conditions are met, socio-cognitive conflict can support learning when the learners start articulating, explaining and elaborating their understanding in a way that supports the development of the task.

The SynergyNet project

The SynergyNet project is developing a classroom environment with networked multi-touch tables for small groups of learners. The project aims to design collaborative learning environments where digital resources and information can be shared easily between learners and with the teacher (Hatch, Higgins & Mercier, 2009). In particular, aspects of the process of learning can also be shared by moving more easily between whole class and small group activity (Blatchford, Kutnick, Baines & Galton, 2003). The intention is to develop uptake and integration of learners' activities and contributions more effectively both at small group and whole class levels (Nystrand, Wu, Gamoran, Zeiser & Long, 2003). One dimension of the design of the environment and software therefore aims to support peer collaboration and interaction in groups.

In this study, we contrasted how small groups collaborated during a consensus-building activity on either a paper-based or a multi-touch version of the same task. We hypothesised that the technology would influence how the groups managed the problem space related to the task, influencing how they developed a joint understanding of the task and their interactions related to knowledge sharing, construction and creation. We explored whether the two conditions had any impact on the levels of reasoning reached during the task, and the relationship between interactions and reasoning levels in terms of the epistemic agency of the group.

Methods

The study design adopted an evaluative methodology that aimed to describe and interpret the interactions of students as they undertook the learning tasks (House & Howe, 1999). Similar to other computer-supported collaborative learning studies, a mixed-methods design was adopted (Teddlie & Tashakkori, 2009), and both quantitative and qualitative data collection and analysis techniques were employed (McAteer, Tolmie, Duffy & Corbett, 1997). A content analysis of students' discourse and interaction constitutes the major form of data collection and analysis. This content analysis procedure was designed to provide quantitative measures of the quality of students' verbal interaction and more interpretive discussion of students' contributions in the different environments.

Participants

Participants were 32 Year 6 pupils (10- to 11-year-olds) with 16 boys and 16 girls in the sample. In terms of attainment, the participating schools' results on national tests are average or just below national norms in England.

In accordance with the ethical approval from the university, consent forms for parents were distributed; teachers selected participants from the students who returned signed consent forms. Teachers were asked to balance gender and to provide a range of participants in terms of attainment.

Pupils were taught in single gender groups of four and led through activities that introduced them to the multi-touch table. One group then completed a multi-touch version of the mystery task, while another group completed a paper-based version of the same task in a different room. Two teachers were involved; each taught half of the paper-based activities and half of the multi-touch activities. Students completed a total of four tasks: three mathematics and one history. All students used the multi-touch table over the course of the day, either for history or for mathematics, and those using the paper-based activities first were told that they would be using the multi-touch tables for the next activity. Levels of engagement in both kinds of tasks were high. This paper focuses on an analysis of the quality of thinking and interaction in the history activity.

The history task

The history task was based on an incident in a coal mine in 18th century North East England—a location and period of history that was familiar to the children. At the start of the task, the teacher read aloud a statement about the accident, in which a 10-year-old boy, Robert Dixon, lost his leg. The children then received 16 clues to help them determine what happened to Robert Dixon and who was responsible for the accident. This task was designed to encourage divergent argumentation, with multiple possible answers.

In the paper-based version of the task, clues were printed on separate small pieces of paper, which were placed in a pile in the centre of the table. In the multi-touch version, the clues were also presented on digital slips of "paper", which were placed in a "pile" in the centre of the screen. The digital paper could be moved to change orientation or the location on the screen (tabletop). They

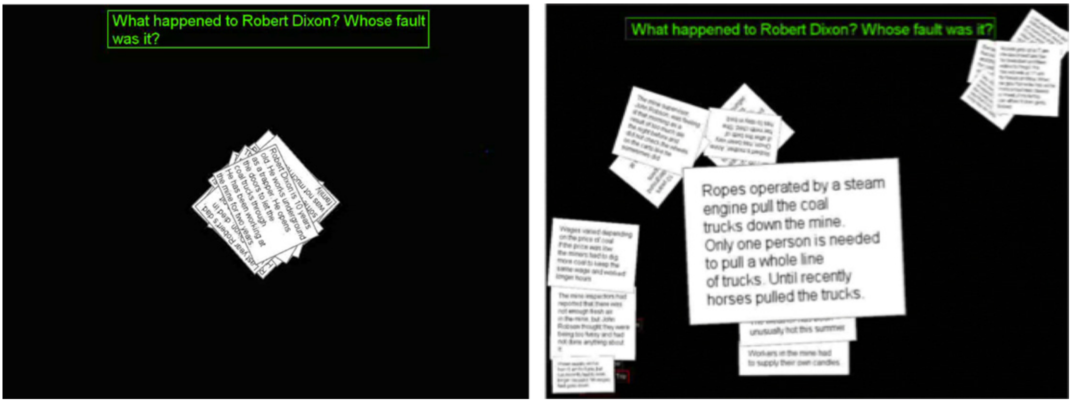

Figure 1: Screenshots from beginning and middle of activity

Figure 2: Photographs of students in multi-touch and paper conditions

could also be enlarged or reduced in size. Figure 1 shows screenshots of the mystery; Figure 2 shows photographs of a group working on the multi-touch table and students working on the paper-based mystery task.

Data and analysis

All activities were videoed and transcribed for analysis. The Structure of the Observed Learning Outcome (SOLO) taxonomy was adapted to assess the quality of reasoning. This taxonomy (Biggs, 1995; Biggs & Collis, 1982) provides a hierarchical categorisation that identifies increasing complexity in reasoning. This classification scheme was selected because it identifies relational complexity as a valuable feature of contributions, rather than simply the type of thinking involved such as synthesis or evaluation (Moseley *et al*, 2005).

We adapted the coding scheme to apply to the task (see Table 1). Each turn was assigned a single SOLO code, reflecting the highest level of reasoning shown in that turn. One author coded the entire data set, while a second author coded two transcripts to ensure reliability. The inter-rater reliability was 92%, indicating a high level of agreement between coders. In the examples that follow, inverted commas and italics indicate the participant is reading aloud from the clues.

An interaction classification scheme was adapted from Thomas (2002) to evaluate the ways in which students were building on each other's ideas during the task (see Table 2). Although Thomas' study examined online interaction, the focus of the study was on knowledge building and the interactive nature of the online messages or "turns", thus the interaction codes are relevant to this study, providing several levels for analysis of students' interaction based on

Table 1: SOLO taxonomy adapted for "Robert Dixon" mystery

	Definition	*Example*
Prestructural	Reading clues	"*the coal mine is the only employer in the village*"
Uni structural	Reading clues, making brief comments in relation to value of the clues	"*Robert had to work from 6am . . .*" that's quite important because he might be tired
Multistructural	Comments on value of clues by referring to other clues within the task (or drawing on prior knowledge)	I think that's why he got run over because he could have opened the door for the cart and one's come past and . . .
Relational	Puts together an explanation of mystery, drawing on clues available	So it's his fault cause he's saying he might have fallen asleep because he was too hot and had to, he wanted to sit down and he just dozed off to sleep and John Robson said "oh well I can't do anything about the fresh air" and he never checked the wheels so it might have been John Robson's fault.
Extended abstract	Puts together explanation of mystery drawing both on clues available and prior knowledge	But it says here that there was an explosion and they all got some money but there was not enough for each family so Robert knew about that because his dad was in it. So he tried to ... Work overtime and get extra money and get his leg cut off and get that money.

Table 2: Interaction coding scheme

	Definition
Independent	Comment does not reference a previous turn
Quasi-interactive	Refers to previous turn, or attempts to draw others in to conversation
Elaborative—interactive	Comment draws on previous turn, elaborating on the content
Negotiating—interactive	Comment puts forward an argument, either in agreement or disagreement with a previous turn
To teacher	Comments directed at, or in response to the teacher
Organisational	Turns that related to organisation of the group or the task
Other	All other comments

Henri's (1992) basic categorisation of independent and interactive comments. To take into account the nature of the task and the in-person interaction, codes for comments to the teacher, organisational comments and comments that were not related to the content were added to the coding scheme. It should also be noted that, unlike the SOLO scheme, this is not a strict hierarchy; both elaborative and negotiating comments being classified as interactive comments, showing more interaction than quasi-interactive and independent comments.

Results

The length of time taken to solve each mystery was calculated from the time the clues were presented to the groups to the time the teacher wrapped up the conversation. Groups took longer to complete the task on paper ($M = 19.89$ minutes; $SD = 5.33$) than on the multi-touch table ($M = 14.62$; $SD = 2.77$), although this difference was not statistically significant ($t(6) = 1.76$, $p = 0.13$). Turns, which were defined as identifiable discourse moves (Sinclair & Coulthard, 1975), were counted for pupils and teachers in each group. Results indicate that there were no statistically significant differences between conditions (multi-touch table/paper) in total number of turns, 241 (*SD* 73)/201 (*SD* 73), number of teacher turns, 71 (*SD* 28)/50 (*SD* 13) or proportion of teacher turns (29%/26%), or number of student turns, 170 (*SD* 61)/151 (*SD* 65). This indicates underlying similarities between the activities and establishes their comparability for the subsequent discussion.

Initial strategies

The first 30 seconds of each task were coded to determine how the groups initially dealt with the clues, with attention paid to the distribution of clues and whether the clues were read aloud. In Figure 3, the number of groups who used each of the three strategies is displayed, showing all the groups in the multi-touch condition using a shared viewing, reading-aloud strategy, while only one group in the paper condition used this strategy (all crowding together so they could read the clues).

One feature of the multi-touch table is that the clues cannot be picked up the way that pieces of paper can. Additionally, the facility to resize the clues was quickly adopted by most groups who enlarged the information to make reading easier, both as individuals, but then for other members of the group to follow along as one of them read aloud. This clearly influences the initial stages of the task and appears to support a more interactive engagement with the content of the task and the process of interaction with the other members of the group.

Examples

Differences in these initial strategies led to differences in the way the groups dealt with the clues, discussing the relevance of the clues at an earlier stage of the process in the multi-touch condition compared with the paper-based condition. The two examples below indicate the different way the groups deal with the clues across conditions.

Example 1: Initial strategies in the multi-touch condition

Sam selects the next clue to read out, enlarges it with a two-handed gesture, and positions it centrally on the table so that others can see it as he reads it out loud. The others look at the clue as he reads.

Sam: *[reading]* "*because of the war, there has been less trade overseas and there is less demand for coal from the factories so the price of coal is very low*" I think that's a red herring. Do yous, do you agree? Do you agree Connor?

As he finishes reading the clue, he makes it slightly smaller (the group have previously agreed that irrelevant clues can be made smaller and moved to one side to indicate lesser importance) and moves it towards Connor as he asks him if he agrees.

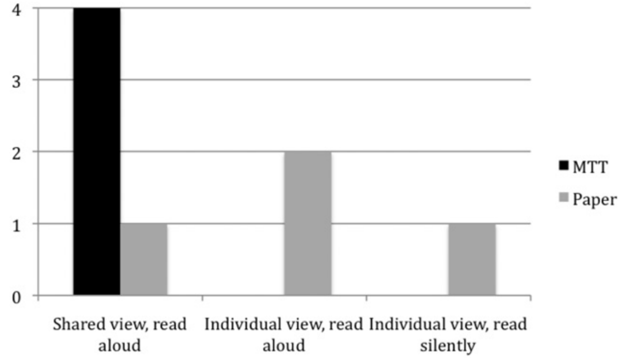

Figure 3: Initial strategies. MTT, multi-touch table

Joe: Yeah
Connor: No. The price of coal is about money, greed.

Connor takes control of the clue and enlarges it again, turning back to Sam and lifting his fingers off as he finishes speaking.

Sam: Why don't we put it in the middle?

Sam moves the clue into the central area of the table, which has previously been identified as where they will place clues they are undecided about. He leaves it slightly enlarged.

Example 2: Initial strategies in the paper condition
The group have handed out the clues that are on pieces of card so that they have a similar number each. They hold up the pieces of card in front of them and take it in turns to read out their clues. They look up when they have finished reading their clue and look to the next person to take their turn.

Sophie: *[reading] "Because of the war there is less trade overseas and there has been less demand from the factories so the price of coal is very low."*

Charlotte: *[reading] "The mine inspectors had reported that there was not enough air in the mine but John Robson thought they were being too fussy and had not done anything about it."*

Sarah: *[reading] "Last year Robert's dad, William Dixon was killed in an explosion at the pit. Fifty-three men and boys were killed. The fund was set up for the families. Sir Charles Richardson the mine owner gave some money but there was not much for each family."*

Type of interaction
Using an adaptation of Thomas's (2002) interactivity coding scheme, the transcripts were coded to examine differences in how the groups interacted.

As can be seen from the variations in means in Table 3, there tended to be more independent and quasi-interactive talk in the paper-based condition than in the multi-touch condition and more elaborative and negotiating talk in the multi-touch condition than in the paper condition. Additionally, it appears that students direct their interaction less to the teacher in the multi-touch condition than in the paper based condition.

Table 3: Mean (SD) amount of each type of interaction

		Multi-touch	*Paper*
Independent	Total	19.25 (6.13)	26 (35.02)
	Proportion	14.48 (7.32)	12.45 (12.67)
Quasi-interactive	Total	20 (9.13)	41 (26.99)
	Proportion	13.55 (3.81)	22.45 (7.39)
Elaborative	Total	31.25 (24.97)	10.5 (13.53)
	Proportion	18.07 (9.63)	6.14 (8.38)
Negotiating	Total	9.25 (10.2)	3.5 (5.19)
	Proportion	5 (5.03)	1.99 (3.25)
To teacher	Total	37.75 (20.9)	59 (21.59)
	Proportion	28.15 (19.6)	37.34 (14.33)
Organisational	Total	18 (7.54)	12.5 (8.89)
	Proportion	11.67 (3.05)	8.29 (4.91)
Other	Total	16.75 (13.52)	15.25 (13.94)
	Proportion	10.73 (5.12)	9.03 (9.29)

SD, standard deviation.

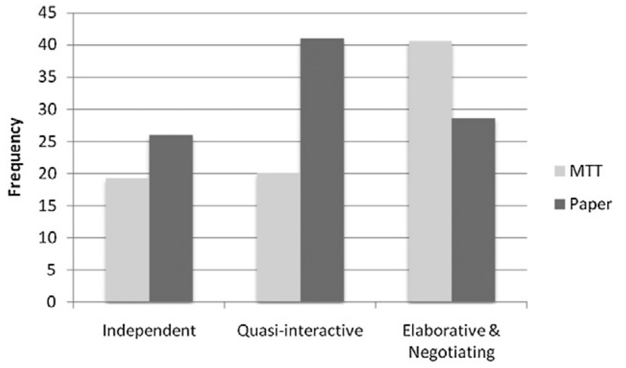

Figure 4: Comparison of interactions. MTT, multi-touch table

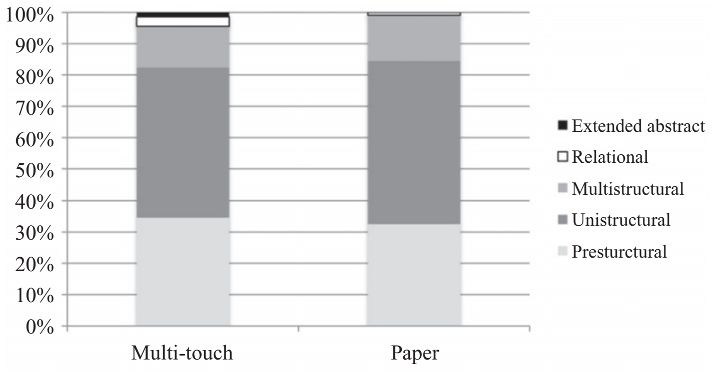

Figure 5: Proportion of types of reasoning across conditions

In Figure 4, the interactive codes have been combined, so that the differences between types of interaction can be seen in more detail.

Level of reasoning

Considering the task and age of the participants, it was not expected that many groups would reach the relational and extended abstract levels of reasoning in the SOLO taxonomy. Results of our coding confirmed this—with only five groups making statements that were coded as relational and only one of those groups making statements that were coded as extended abstract. Figure 5 shows the types of reasoning across conditions where little difference is seen between the multi-touch and paper conditions for this task. Analysis indicated no statistical difference between the conditions, although again there was considerable variation between groups.

Examples of types of interaction and reasoning

The interaction and SOLO coding schemes were applied independently and were then compared to identify any patterns indicating a relationship between the type of interaction and level of reasoning. This allows us to draw comparisons between the level of reasoning reached within a group and the types of interaction that the group was engaging in and begin to hypothesise about whether changes in interaction in the different conditions supported collaborative knowledge building. As can be seen in Examples 1 and 2, groups in the paper condition had more independent types of interaction during the beginning of the task, while groups in the multi-touch condition had more quasi-interactive interactions. As would be expected, prestructural and unistructural reasoning, as identified by the SOLO taxonomy, tended to occur during independent and quasi-interactive types of interactions.

In Example 3, which is drawn from a group in the paper condition, the students are mostly engaged in reading the clues and organising who reads the clues, and they begin to interact over the meaning of the phrase "not against the law." This type of interaction pattern was common across all the groups, as the pupils tried to make sense of the task and whether or not the clues were relevant, although differences emerged across conditions as described in the initial strategies section. In this example, it is also clear to see how the relatively low level of interaction is associated with low levels of reasoning. Another advantage of the multi-touch surface was that clues that were deemed unimportant could be made smaller, whereas clues that were considered important or undecided could be left enlarged so that they could be referred to and read again easily. The clues therefore continued to be used longer in the multi-touch condition. By contrast, in the paper-based condition, the children tended to hold the clues as they read them individually then placed them in a pile for relevant or irrelevant without the other children looking at them. Their interaction therefore tended to focus on group management and turn taking rather than the content of the task.

Example 3: Reasoning with interaction coding

Transcript		SOLO	Interaction
The children have divided up the clues and are taking it in turns to read them out. Georgia picks up a clue and begins reading.			
Georgia:	*[reading]* "*Robert usually works from six am to six pm but recently he has had to work longer because his wages have gone down.*"	prestructural	independent
Lucy:	This one is about Robert.	prestructural	independent
Molly:	This one's about his family.	prestructural	independent
Lucy and Molly each refer to the clues they are holding.			
Lucy:	Oh right. Read it Molly		organisational
Molly:	It's Amy's turn		organisational
Amy:	Erm I haven't got . . . *[reading]* "*At this time it was not against the law for a ten year old boy to work underground.*" So we know that he should have been down there so . . .	unistructural	independent
Molly:	No he shouldn't or . . .	unistructural	quasi-interactive
Amy:	No he should have because it says at this time it was not against the law so against the law means . . .	unistructural	quasi-interactive

In Example 4, from the multi-touch condition, the pattern of an independent, prestructural statement being built on by a combination of unistructural statements with each trying to make sense of the prestructural statement can be seen. Here, James and Jack develop their ideas through a series of elaborative statements, leading to a multistructural statement where Jack pulls together the idea of Robert's job as a trapper, with a piece of information about the illness of Robert's mother that had been discussed earlier, with James' idea that someone else might have opened the door, as Robert was too busy to do so, catching Robert's leg, and causing the accident. The independent statement that Daniel makes at the beginning of the example is elaborated on by

James and then Jack, a pattern we see repeated again, after Daniel's quasi-interactive comment. These higher levels of interaction co-occur with a more complex level of reasoning in Jack's final statement, as he tries to draw together their thinking on the task.

Example 4: Building on reasoning through interactive statements

Transcript		SOLO	Interaction
Daniel:	*[reading] "He works underground as a trapper. He opens . . ."* We've never had that [piece of information]	prestructural	independent

As Daniel reads aloud, the other three children look at the digital clue. As he finishes, he reduces the size of the clue and moves it into a central position on the multi-touch table.

James:	No and that could be relevant because he opens the doors, he's the one who opens them to let the trucks out but he never done it then though . . .	unistructural	elaborative
Jack:	Because he was too busy working.	unistructural	elaborative
Daniel:	I'd say red herring.	unistructural	quasi-interactive

Daniel moves the clue off to one side to a "pile" of clues they have decided are not important.

James:	Someone else did it then though.	unistructural	elaborative
Jack:	He was too busy working to get money for his Mam's medication	multistructural	elaborative

Jack mimes working with a pick at the coal face as he talks.

In the final example, also from a group in the multi-touch condition, we see a more complex and less common set of interactions where an initial clue leads the group to discuss reasons for who was responsible. Sam has taken the view that Robert intentionally caused his own accident, as they had learned that miners received compensation after an earlier accident. While Connor agrees that the earlier compensation was part of the issue, he blames the mine manager, John Robson, who would not have received the earlier compensation, and thus was jealous of Robert's family. In this example, we see that as Sam and Connor both try to negotiate their position, they ignore Jordan's attempts to bring in the possibility that the conditions down the mine might have played a part in the accident. This example, again, shows an increasing level of interaction (from independent to elaborative and negotiating comments) that allows the group to move from lower levels of reasoning about a single clue to integrating multiple clues and bringing in prior knowledge to make sense of the task.

Example 5: Mixed levels of interaction and reasoning within a group with multiple competing ideas

Transcript SOLO Interaction

Sam selects the next clue to read and indicated to Joe that it is his turn. Sam enlarges the clue and points to the words as Joe reads it out loud. Jordan corrects Joe's reading of "unusually."

Joe:	*[reading] "The weather had been unusual hot this summer."*	prestructural	independent

As Joe finishes reading, Sam shrinks the clue but pauses as Jordan disagrees and enlarges it again slightly. As Sam attempts to move the clue, Joe places his hand over Sam's to stop him.

Transcript		SOLO	Interaction
Sam:	I think that's a red herring.	unistructural	quasi-interactive
Joe:	That's a red herring that.	unistructural	quasi-interactive
Jordan:	I don't think so because when it's hot you get all tired and that.	unistructural	negotiating
Connor:	Aye you get [inaudible]	unistructural	elaborative
Sam:	I don't think he fell asleep because like I think he done it for money.	multistructural	negotiating
Teacher:	We've got two ...		
Connor:	I think it was Robson.	unistructural	independent
Sam:	Because it says, Robert Dixon, oh no, where is it?	unistructural	independent

Joe shrinks the clue he has just read, while Sam looks at the clues they have already read out and moves one towards the centre of the table and begins to read it out loud. The others look at the clue as he reads it.

Teacher:	We've got two . . .		
Sam:	*[reading] "Last year Robert's dad, William Dixon, died in an explosion at the pit. Five hundred, I mean fifty three men and boys were killed. A fund was set up for their families . . ."* but he gave some money, like he might have been wanting the money because he knows his dad died in an accident and that they give money to families so . . .	relational	independent
Connor:	I think it was John Robson because he might not have got any money and he might have been jealous.	relational	negotiating

As can be seen in Examples 3, 4 and 5, the fact that the clues were available in a different format across the two conditions appears to have influenced the nature of the interactions around the clues, and there is a clear and expected relationship between more interactive comments (negotiating or elaborating) and higher levels of reasoning. When the clues can be resized and moved to the centre of the table, groups are able to maintain joint attention on the clue, which can support a more interactive level of engagement with the content and more complex reasoning.

Discussion

This study set out to examine differences in collaborative interaction between groups working with a traditional paper-based mystery task and groups using multi-touch tables to solve the same task. Examining the differences between conditions across the different measures both qualitatively and quantitatively provides insight into how these activities, which use features of this emerging technology, may influence collaborative interaction.

While there was no statistically significant difference in the length of time taken, examining means indicates that the groups in this multi-touch condition took almost 25% less time than groups in the paper-based condition. As groups in the paper-based condition did not reach a higher or more complex level of reasoning than groups in the multi-touch condition (as indicated by the SOLO analysis), the extra time spent on the task in the paper-based condition does not appear to be due to a deeper engagement with the content. Instead, our analysis of the initial strategies used by the groups suggests that learners in the multi-touch condition were able to create a shared understanding of the task more quickly than groups in the paper-based condition,

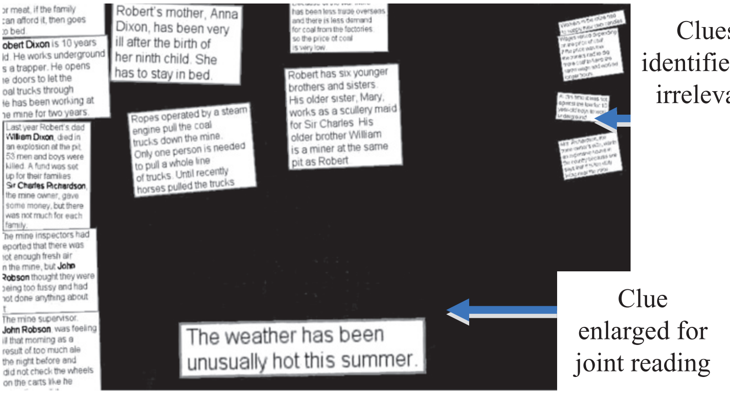

Figure 6: Screenshot of clues on the multi-touch table

creating a better foundation from which they could discuss the topic. Comparison across all the groups suggested that groups in the multi-touch condition engaged in more shared viewing of the clues while the groups were becoming familiar with the clues, that they were able to help each other or correct each other when one child was reading aloud, and also that they discussed the clues as they read them rather than reading through all the clues and then discussing their relevance as illustrated in Examples 1 and 2. This is likely to be a result of one of the constraints of the multi-touch display where the clues have to be left on the table surface and cannot be picked up, so encouraging joint attention and a more constructive approach to using the information (Webb, Troper & Fall, 1995). The additional feature of being able to enlarge the clues to read them aloud also appeared to support this shared attention.

The importance of developing a shared understanding of the task is highlighted in numerous prior studies that examine collaborative learning (eg, Roschelle, 1992; Jeong & Chi, 2007). By creating a more effective joint understanding of the task, the members of the group were more clearly able to discuss the options or, as seen in Example 5, to argue about their different interpretations of the clues. The multi-touch table also allowed members of the groups to move and resize the clues in a manner that is not possible with actual pieces of paper (see Figure 6). This affordance facilitated the joint attention we saw in the analysis of the groups' initial strategies and seems likely to have facilitated the quicker development of a shared understanding of the problem. Groups in both conditions used the table space available to them to organise their clues; however, in the multi-touch condition, the groups also resized the clues to signify importance. This made their physical structuring more visible to all group members and represented the history of the discussion and the consensus reached on the table surface. These differences suggest that the multi-touch environment facilitated a different type of interaction over the clues and that these variations changed the group process, particularly in the early stages of the task, to a more dialogic pattern of interaction (Wegerif, 2006). The learners responded to and built on each other's ideas in an exploratory way by discussing and debating the contributions of different group members.

Conclusion

Research on collaborative learning tells us that groups who build on each other's ideas, engaging in mutually responsive conversation about their task, are more likely to solve problems successfully and learn from the experience (eg, Barron, 2003). Our data indicate that groups in the multi-touch condition were better able to engage in this type of interaction starting from the initial strategies that they used to support their elaborations and negotiations over the clues. While further research is needed to validate this finding with a bigger sample and across different activities, the findings indicate that this feature of the multi-touch table supported collaborative interaction more effectively than the paper-based version of the task.

This analysis suggests that a number of the design features of large multi-touch surfaces and the design of specific task environments are supportive of collaborative interaction. The facility for several people to interact with the surface at the same time is significantly different from the single point of control provided by other technologies such as a computer and mouse or interactive whiteboard. The support that the design of the interactive surface provided for the creation of joint attention by restricting the information to a single visible plane in common view as well as the design of the task using multi-touch features for positioning and resizing for relevance and importance both appear to be beneficial in the joint construction of understanding in this kind of collaborative activity.

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