Actions Speak Loudly with Words: Unpacking Collaboration Around the Table

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ABSTRACT

The potential of tabletops to enable groups of people to simultaneously touch and manipulate a shared tabletop interface provides new possibilities for supporting collaborative learning. However, findings from the few studies carried out to date have tended to show small or insignificant effects compared with other technologies. We present the Collaborative Learning Mechanisms framework used to examine the coupling of verbal interactions and physical actions in collaboration around the tabletop and reveal subtle mechanisms at play. Analysis in this way revealed that what might be considered undesirable or harmful interactions and intrusions in general collaborative settings, might be beneficial for collaborative learning. We discuss the implications of these findings for how tabletops may be used to support children's collaboration, and the value of considering verbal and physical aspects of interaction together in this way.

Keywords

Collaborative learning, children, user studies, framework

INTRODUCTION

The potential of multi-touch tabletop computers to enable groups of people to simultaneously touch and manipulate a shared tabletop interface provides new possibilities for collaborative learning. Previous research suggests such technology is enjoyable to use, promotes playfulness, can encourage equity of participation and can lead to learning [6, 7, 14, 17]. However, recent studies on collaborative learning around tabletops have shown the effects to be small or insignificant when compared with other technologies [6, 7]. In this paper we examine why this might be the case by unpacking collaboration around the tabletop to reveal subtle mechanisms at play. We argue that this fine level of analysis is critical to understand how tabletops can or cannot support collaborative learning.

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Previous research [17] has showed how physical actions and types of discussion are indicative of productive collaboration. However, little is known about the relation between physical actions and aspects of discussion in relation to collaborative learning. In this paper we present the Collaborative Learning Mechanisms (CLM) framework which we use to consider both verbal and physical aspects of children's collaboration as they complete a design task around a multi-touch tabletop. In so doing, we reveal how effective collaborative learning in this situation involves the close coupling of physical actions and verbal discussion. This has implications for how multi-touch tabletops can be used to support children's collaboration and stresses the value of considering both verbal and physical aspects of collaboration together to understand how learning takes place around tabletops.

TABLETOPS AND COLLABORATIVE LEARNING

Multi-touch tabletops have been explored for a variety of uses, though much research is concerned with investigating the potential of tabletops, and in developing new ways of interacting with and around them [e.g. 3, 23]. However, within education, the potential of these technologies to enable groups of people to simultaneously touch and manipulate a shared tabletop interface is only just beginning to be researched in terms of whether they can facilitate collaborative learning. For example the SIDES project [15] found they were able to support adolescents with Aspergers Syndrome to practice effective group work and StoryTable [4] encouraged groups of children to work together to develop narratives with high cohesion. Other research has looked at the potential of tabletops to support collaborative exam revision [14], learning with a mind-mapping application [6], and children conducting a collaborative design task [7, 16]. This research indicates that tabletop computers, while being engaging and enjoyable to use during collaborative learning activities [6, 14], did not always produce significant learning gains [e.g. 6, 7]; Do-Lehn et al. [6] found that in comparison to an augmented tabletop surface, a traditional interface with a single mouse input led to closer working and more discussion, which led to greater learning gains [6].

Instead, it appears that learning benefits are subtler: being revealed as part of the learning process rather than the outcome per se. For example, it has been suggested the multi-touch tabletop encourages playfulness in interaction: [14] found there were more examples of participants 'having a go' to come up with answers to problems they were unsure about in comparison with groups using paper materials. Further, tabletops have been found to support equitable participation in learning situations (i.e. a similar amount of participation from each participant) [7, 14, 16] - in particular where use is made of features of the DiamondTouch tabletop to enforce turn-taking or require joint actions [4, 15].

UNDERSTANDING COLLABORATION AROUND THE TABLETOP

In previous research on collaborative learning, improved learning outcomes, shown by pre-and post- test scores, have been reported as evidence that effective collaboration has occurred using the particular technology [6, 14]. However this approach is of limited value in telling us how collaboration occurs or why it is effective. An alternative approach, therefore, is to consider aspects of the process of working that suggest enhanced collaboration was occurring: for example, the equity of participation, and the amount and type of discussion occurring.

There is evidence to suggest that various types of talk are indicative of more effective collaboration in terms of learning in groups of children [e.g. 22]. Previous work which considers discussion as a means to analyze the process of collaborative learning around tabletops has so far reported on general patterns of talk that occurred across different conditions [6, 7, 14] or over time [15]; there is little description of how these types of discussion relate more immediately to other aspects of interaction around the tabletop.

The aim of our paper is to show how the combination of language *and* action is important to tabletop facilitated collaborative learning. Teasely and Roschelle suggest that, "one major role of the computer in supporting collaborative learning is in providing a context for the production of action and gesture" [18, p238] and argue that actions and gestures can serve as presentations and acceptances: for example, one person may interpret another's utterance by performing an action (an acceptance); or use their hands to demonstrate an idea (a presentation). Further, the 'mechanics of collaboration' [13] have been suggested as important in understanding how people collaborate around tabletops, though so far have not been used to analyze collaborative learning. These mechanics describe not only how people discuss around the tabletop, but also how they write and gesture to communicate with others, and how they glean information from a variety of sources including what people are doing, where they are doing it, and changes to digital objects on the tabletop.

To analyze collaboration around a tabletop in terms of both verbal discussion and the physical actions and gestures which complement such talk, we now present the CLM framework. Based on the psychological and learning literature on collaboration, it outlines mechanisms considered important for collaborative learning. These are (1) mechanisms of collaborative discussion, and (2) mechanisms for coordinating collaboration.

1. Mechanisms of Collaborative Discussion
• making and accepting suggestions
• negotiating
2. Mechanisms for Coordinating Collaboration
• joint attention and awareness
narrations

Table 1: The Collaborative Learning Mechanisms framework

1. Mechanisms of Collaborative Discussion

Making and accepting suggestions: Kruger [9] found pairs of children who talked constructively together, introducing knowledge and ideas to the other member and accepting information from their partner, outperformed those who did not. Others have found task focused discussion (including: making and asking for suggestions; giving and asking for opinions; and asking for information or clarifying or repeating what others have said) can predict task performance [1, 22].

Negotiating: Much research emphasizes the importance of negotiation of ideas in effective learning discussions [5, 18]. For example, Mercer and Wegerif found exploratory talk - "talk in which partners engage critically but constructively with each other's ideas. Statements and suggestions are offered for joint consideration. These may be challenged and counterchallenged, but challenges are justified and alternative hypotheses are offered."[11, p85] - associated with better learning outcomes.

2. Mechanisms for Coordinating Collaboration

Joint attention and awareness: Effective collaborative learning also requires coordination: mechanisms are required to monitor ongoing activity and recognize where there is a breakdown or conflict (for example, where two people do not agree on what they are doing) in order that it can be repaired [18, 20]. To achieve this, each participant must be aware of what the others are doing and thinking, either by jointly attending to the problem, or by being aware of everything going on.

***Narrations**:* Roschelle and Teasley observed that one way participants coordinated working was through 'narrations'. This is where participants say out loud what they are doing in order to enable the monitoring of each others' activities. The Mechanics of Collaboration describe similar mechanisms of talk they refer to as 'verbal shadowing' [13] or 'alouds' [21].

Our CLM Framework is intended to be used for analysing both physical and verbal aspects of collaborative learning by drawing attention to particular categories of behaviour associated with effective collaborative learning. Next we show how it was used to conduct a detailed analysis of the collaborative interaction around a tabletop that took place during a study of OurSpace.

THE CASE STUDY

The OurSpace application was designed to allow groups of young school children (aged 7-9) to plan their classroom layout using a multi-touch tabletop. The small DiamondTouch tabletop was used, measuring 65 x 49cm, which allows multiple participants to touch and use it simultaneously.

OurSpace was used to present children with a plan of their own classroom, a set of to-scale desk icons and a set of student icons. By touching the student and desk icons, the participants can drag them into the classroom plan and arrange desks and seat students at them how they want (see Figure 1). Desks can be rotated on the yellow turntable (rotator) icons in the corners, Student icons have non-gender-specific names and represent an imaginary class that it is suggested might occupy the participants' classroom next year. To provide the children with criteria to discuss, the student icons were given various attributes (see Figure 2): their colour represents the friendship group they belong to; a speech bubble indicates the student is talkative; and a pair of glasses they are short sighted (N.B. Even though wearing glasses means their eyesight is corrected it provided a good discussion point). For more details of how the system worked, see [16].

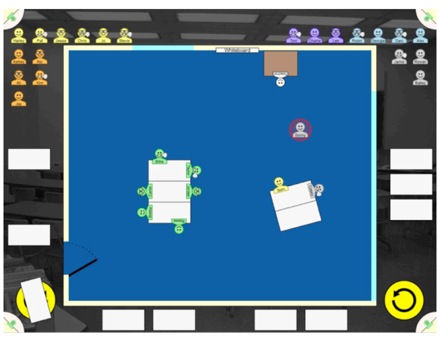

Figure 1. OurSpace classroom plan part way through task with unplaced desks and student icons around the edge

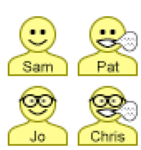

Figure 2. Four friends: 2 who are chatty and 2 wearing glasses

The study was conducted in an urban primary school in the southeast of England. In total, 27 children (12 boys and 15 girls) participated in the study from one Year 3 class and one Year 4 class. The Year 3 children were 7-8 years old, and Year 4 children 8-9 years old. Teachers were asked to group children based on two criteria: gender and those who would work well together. This resulted in 9 same-gender same-year groups of three (5 groups of girls and 4 groups of boys).

The tabletop running OurSpace was set up in a quiet room in the school, and children were taken out of class in their groups of three to participate in the sessions. At the beginning of sessions children were introduced to the multi-touch tabletop to ensure they understood what the icons and floor plan represented, and shown how to use it and the application (i.e. how to move student and table icons etc.). They were then asked to work together to create a table and seating arrangement for next year's class.

Video recordings were made of sessions from two angles: one from directly above the table to capture movement of icons and interactions on the surface of the table; and the other from the side to capture whole group and body interaction around the multi-touch table. These two angles were later synchronized with a single sound track to support identification of the aspects of collaboration described in our framework, and analysis of discussion and physical interactions around the table at these points.

FINDINGS AND ANALYSIS

Previously reported findings of OurSpace [7, 16] focused on whether multi-touch was beneficial for learning compared with a single touch interface (i.e. with input restricted to one user at a time). It was found that there was more task-focused talk in the multi-touch condition and more turn-taking talk in the single-touch condition. However, there may have been more awareness of each other's actions in the single-touch condition for some age groups of children. No differences were found between these conditions in verbal equity of participation, or physical equity (both in terms of how many touches each child made or in the distribution of these touches as determined by log-file analysis). Whilst in this research both talk and physical interactions were considered, the findings were based on how much of the various types of talk occurred in each condition, and the number of touches by each participant – not how talk and physical actions related directly to each other during collaboration.

In the analysis presented here, we use the CLM framework to identify aspects of effective collaboration around the tabletop when used in multi-touch mode, and consider the role physical actions and gestures play in complementing discussion in these instances.

Making and Accepting Suggestions

In all groups the majority of exchanges observed were task focused and related to the design of the seating plan. This talk included many examples of the kind of task focused talk indicative of collaboration [11, 22]. For example, participants made suggestions for how the classroom should be arranged:
"Let's put chatty ones near the front"

They asked each other's opinions:
"I think we should make it easier for people to get through the classroom as well. Do you think that's a good idea?"

They also clarified or repeated what others had said to ensure they understand, for example:
B: "Talkatives…I'm gonna put talkatives on here."
A: "Talkatives!"
C: "What everybody that talks on that table?"
B: "Yeah!"

When analyzing the physical actions accompanying such talk around the tabletop, we observed these comments were commonly coupled with some *physical gestures* to ground them:
"you put the chatterbox like there so that then the teacher can see them and erm they'll get told off" [*points to relevant areas on table-top*]

They were often coupled with *manipulation of the interface* as participants actually showed or demonstrated their ideas to each other:
"I think you should put that one on there" [*moves piece in question*]

These snippets and others from the transcripts suggest that the multi-touch tabletop provides a context for the production of action and gesture to support language as 'presentations'. We also observed evidence of actions serving as 'acceptances', as in the example below where B acts out C's suggestion for them all to assess:
C: "Yeah. Oh that will just be it. I think we should turn the tables that way *[gestures for the tables to be rotated 90 degrees]*.
B: "What do you mean?"
C: "Like…"
A: "What we could put that…No!"
B: "No wait Hannie! What so they're like…"[*A and C stop and watch what B is demonstrating (the table is on the rotator)*]
C: "Yeah that like that! Yeah cos then they…"[*Table icon turns into position which C was thinking of]*
A: "Then they can all see can't they." *[A agrees and so B and C then continue idea by rotating tables. A watches for a short while and then joins in.]*

Negotiating: Undoing, Blocking and Grabbing

Language and action also worked in tandem around the tabletop to support *consideration and discussion of other's ideas*. This is illustrated in the next example where the participants are making and responding to each other's suggestions, grounding them with gestures to and actions on the tabletop:
A: "I've just added another table and it's already full. I need to…" [*A adds another table to the group of tables she has been working on to fit the rest of the 'chatties' (i.e. talkative student icons) on*]
C: "But he needs to be with his friends so I would put two friends there." [*Alerted to what A is doing by her announcement above, C makes a suggestion for where some of the student icons should go, and points to illustrate.*]
A: "Yeah."
B: "He doesn't have to be, he can be next to his friends. Can't he?" *[All participants are now discussing the same area of the table]*
C: "She's, she's not near, not near his friends."
A: "Oh he's fine, he's a chatterbox."
B: "Yeah they're all chatterboxes."
C: "Or he could be there and put one of his friends there."*[C is making an alternate suggestion]*
B: "They could go a bit like over here. "[*As he says this, B starts to move all of A's tables to the side*]

The observation of the participant's undoing each other's work was surprisingly common: they often moved icons that other children had placed at a table to illustrate their own ideas. For example, in this extract from another group, the same child icon was passed back and forth twice between two table positions as the participants discussed where best to place it:
B: "We need not chatterboxes" [*B places a (non chatterbox, orange) student icon at a table (with lots of other chatterboxes)*]
C: "That one's a bit lonely because it's an orange one and they're not chatterboxes" *[C moves the same icon to a table with other orange students <UNDOING>]*
B: "But that doesn't matter 'cos they're also with friends" *[B moves it back again <UNDOING>]*
A: "Yeah but that's quite unfair because he's not a chatterbox. So he should sit with his friends" *[A steps in on C's side, and moves it back to where C had put it. <UNDOING>]*
B: "Yeah but then he might have the tempt to talk"
A: "But he's not a chatterbox"
B: "Yeah I know but that doesn't mean he doesn't talk" *[B gives in and A and C's placement stands]*

Here we see how moving already placed icons back and forth enabled the participants' to see alternatives and possibly imagine other options. However, in some situations, undoing another's work triggered 'fighting for control' behaviour, where a participant would try to prevent another from taking 'their' icon [10]. These included *blocking behaviours* such as knocking the other's hands out of the way to prevent them moving icons, and physically blocking off an area of the table. A more subtle mechanism used was to hold a finger on an icon to prevent others taking over its control (the first touch on an icon retains control over it until let go). This occurred in the next example (which follows from the first example in this section), as participants B and C begin undoing A's recently completed work in order to put their own ideas forwards, causing A to 'block':
C: "Why don't you put that on there so this one can go there…" [*C moves one of the people on A's table to a different place at the table <UNDOING>]*
A: "No because it needs to go…"[*A realizes her table has been altered – moves the person C moved out of the way and replaces the table B had moved away*]
C: "…with his friends and then this one can go with his friends."
A: "Yeah, wait a sec." [*B is trying to move the table away again, but A prevents this by holding her finger down on it <BLOCKING>*]

As B is prevented from physically moving the table icon by A, she is required to verbally explain why she had wanted to move it before A understands and allows the reorganization to stand, leading to a convergence of understanding between all three participants:

B: "No, but that doesn't go there because then they will be…won't they? So…" *[B begins to try and explain why she's trying alter A's table]*
A: "But there needs to be chatties." [*A puts forward her own point of view*]
B: "Yeah."
B: "Right I think we shouldn't have all the chatty ones together because then it's just…"
A: "Oh yeah! Because they're all, they will chat!" [*A finally sees B's intention, and allows the alteration of the table to stand.]*
B: "Yeah then they could all chat so…"
C: "So don't put them with their friends!"

A's blocking can be understood as a physical aspect of the discussion, and part of the process of negotiating ideas. Further, the (physical) blocking behaviour A used seemed to act as a trigger to B to (verbally) explain her ideas more thoroughly, leading in this case to agreement between all participants which enables them to progress with the task. Therefore, in this example both participants' verbal and physical interactions around the table contributed to their evaluation of suggestions and negotiations of ideas.

Similarly, in the next example, B uses another blocking technique - grabbing A's arm - to stop A moving the icon he has just placed:

B: "I think all the blind people should be near the board so they can actually see." *[B places a student icon close to the front of the room]*
A: "Yeah"
A: "but that's really not a very good place, you know in class…" [*A points to the student icon B has just moved, and tries to explain why it's not a good placement]*
[Brief interruption]
A: "No, no because they can't! No, no Joe!" [*A points again to the student icon but B grabs his hand to stop him. <BLOCKING>]*
C: "If you want me to be useful! "[*C seems to be feeling left out*]
A: "Shh. In class remember the people who sit on this table can't see the whiteboard as well so they end up sitting on other tables or looking at the computer over here which there isn't so…"*[A manages to explain more fully why they should move B's icon]*]
C: "Well why, why don't we put them there by the whiteboard?" *[C points to a better location at the front of the room.]*
A: "Yeah"
A: "let's put a table here."
[*All three participants are in agreement now and begin taking action on C's suggestion*]

Again, in the above example, B's blocking encourages A to explain to him why he thinks it should be moved. C then steps in with an alternative suggestion that they are all happy with.

Verbal exclamations were also used to play a role very much like (and often in conjunction with) physical blocking techniques, as in the next two examples:

"No, no, no. I've got a really good idea (B), put them back. OK? Put him back, put him back!" *[A appeals verbally to B to put back something he has just undone]*

"Wait, wait, wait, wait, wait!" [*Shouted by A as he rotates a table on the rotator whilst holding B's finger to block him from interfering*]

Whilst such 'blocking' behaviours might be viewed as examples of negative interaction between participants, considering the verbal discussion which accompanies them reveals that in many cases they can be seen as physical 'parallels' to verbal negotiation, and as such part of the process of considering each other's ideas. Although the multi-touch tabletop enables simultaneous interactions and the undoing of each other's work, which sometimes leads to 'fights for control' of digital icons, this can trigger verbal exchanges indicative of effective collaboration.

Coordinating Collaboration: Joint Attention and Awareness

Since the tabletop allowed multiple touches to register, participants would often all be interacting with it at the same time. This in theory meant it was possible for participants to act individually which may not be conducive to effective collaborative learning if participants are not aware of what each other are doing [18]. However, we observed that periods of completely individual working were few and usually short lived. In most groups there were examples of participants working for periods of time closely together - where all were focused and discussing around one area of the table and task - and periods where they worked more independently and in separate areas of the table. There were also states between these extremes, and much movement between these states at the task progressed.

By looking closely at verbal and physical interactions around the tabletop, we observed a number of mechanisms which participants used to coordinate their working and maintain joint awareness, and additionally a number of ways in which the tabletop and task encouraged them to work more closely together. Some of these we have already mentioned. For example, children spoke and physically showed their suggestions at the same time. They also listened to and stopped to watch each other's combined verbal and physical suggestions. Hence, this shows how the tabletop was a shared resource around which they could gesture and move icons to illustrate their ideas and understandings as they described them to each other.

In addition we observed some accidental mechanisms at play which may account for why completely individual working was generally short-lived, despite the tendency for participants to interact with the tabletop simultaneously. For example, due to a combination of the tabletop and task, children often had to reach over each other to pick up icons at the other side of the table. Surprisingly, this did not

appear to annoy or disrupt them too much, although it did result in arms getting in participant's faces and blocking views, causing small pauses in activity. Whilst disrupting the flow of interaction would not usually be considered desirable, there were occasions which illustrate how such disruption of one participant's activity by another can lead to closer working and joint awareness. For example, the following excerpt illustrates how passing an icon across the table-top brought all three participants focus together for a while after a period of working individually:
C: "There's a chatty person." [*C pushes a 'chatty' student icon across the table towards A (as 'chatties' have been allocated A's job). In doing so the icon ends up in B's way*]
B: "Oh they're chatty… *[B moves the icon out of her way…]* So, don't put all the chatty people together." *[then makes a relevant suggestion]*
A: Yeah that's what I do."

Similarly, in the next example, where again the participants are working individually in separate areas of the table, the act of B reaching across the table triggers a period of closer working:
C: "I'm going to do the yellow" [*C comments whilst focusing on her own part of the task*]
A: "Put another table" [*A is focusing on her own part of the task*]
C: "Oh you're doing the yellow" [*C goes to reach for a yellow student icon, and sees B's arm reaching over and taking one of the yellow students to her own table*]
B: "No, I'm doing the glasses people" [*B explains to C what she's doing*]
C: "(B) you're not meant to do that cos they're not friends all of them. (B)'s putting people who aren't friends on each other's table!" *[C responds to B, explaining why that is not the way they had agreed to lay out the room, and draws A's attention to the fact that B was not doing what she was supposed to]*

Although neither of these examples led to valuable exchanges in terms of the task, they illustrate how, that in the same way as narrations can intrude on an individuals working and direct their attention to a shared goal, so, too, can physical actions.

Narrations

There was evidence of children using narrations: verbalizations which enable others to monitor you. For example, even in periods of less close working participants talked almost constantly, continuing to make suggestions and occasionally asking opinions of others, but often without receiving or waiting for the response of their collaborators:
A: "Shall we have another table down there? [*points to space in classroom and looks up to see others response, but gets none immediately*] I'll do a table of three down there" [*he now begins moving tables into place*].

Sometimes it sounded like participants were simply telling others what they were doing, or justifying the physical action they were conducting at the time:
B: "I'll put everyone with glasses in one place, and everyone who's smiley in another place." *[said whilst beginning to do just that]*.

Despite many going unanswered, and regardless of participants' intentions in making them, such suggestions and verbalizations served to keep participants aware of each other's actions: evidence of this were examples observed of a move from less to more close working occurring when a participant *did* respond to a comment made by another.

GENERAL DISCUSSION

The CLM framework was used to identify actions and interactions associated with effective collaborative learning. By considering the role physical actions and gestures play in complementing discussion, we were able to unpack collaboration at the tabletop to reveal some of the subtle mechanisms at play when children are asked to work together on a task. We now present an extended version of the CLM framework which outlines verbal and physical mechanisms associated with effective collaborative learning around a multi-touch tabletop, thereby providing a bridge between previous tabletops work[e.g. 13, 21] and collaborative learning literature [e.g. 11, 18, 20, 22].

Mechanisms of Collaborative Discussion and Action	
Verbal Aspects	**Physical Aspects**
Making and accepting suggestions	
Presentations: - Making verbal suggestions and giving opinions Acceptances: - Listening to others' suggestions and opinions - Asking for clarification of verbal or physical suggestions	Presentations: - Use of gestures such as pointing at tabletop icons to ground talk - Demonstrating ideas by moving icons Acceptances: - Watching others' suggestions - Demonstrating others suggestions for clarification
Negotiating	
Making, listening to and responding to each other's suggestions as above	Watching and responding to each other's suggestions as above
Making alternative suggestions	Demonstrating alternatives - (Undoing)
Disagree *(below can all serve to protect own ideas)* Explanation of own ideas Justification of own actions Verbal blocking: telling others to 'stop' or 'put it back'	Undoing Physical blocking (to prevent undoing, and make time for verbal explanations or justifications) - Knocking hands out the way - Shielding an area of the table - Holding finger on icon

Mechanisms for Coordinating Collaborative Discussion and Action	
Maintaining joint attention and awareness	
(Mechanisms of collaborative discussion and action as above) Narrations: can inform others about your actions	(Mechanisms of collaborative discussion and action as above) Intrusions: physically disrupt others actions which can inform others about yours

Table 2. Extended CLM: Mechanisms around a multi-touch tabletop

Our findings have implications both for ways in which multi-touch tabletops may be used to support children's collaboration, and also for the value in using our framework to consider both physical and verbal aspects of collaboration together to understand collaborative learning around tabletop computers, and potentially in other educational settings. Firstly, we found evidence of verbal and physical parallels: participants used the tabletop for gesturing to and demonstrating their suggestions as they made them, and to respond to other's suggestions. It also enabled us to understand that certain behaviours, while on the surface appear negative, actually had a beneficial effect for the ongoing collaboration. For example, the physical disagreements that took place - in the form of blocking behaviours – when understood as physical parallels to verbal negotiating, showed how they enabled the children to evaluate and consider others' ideas. This is indicative of effective collaborative learning [11, 22]. In some cases these physical blocking behaviours seemed to prompt verbal explanations as participants protected their own suggestions. Dillenbourg [5] discusses the importance of leaving enough space for misunderstanding to sustain participants' efforts to overcome miscommunication. Here it seemed that allowing children to undo each other's work in the process of demonstrating their ideas often caused some misunderstanding, but in turn prompted them to build explanations and justify themselves.

We also found that there were both physical and verbal aspects involved in children's coordination of their collaboration around the tabletop. For example, children maintained joint awareness, essential for effective collaborative learning, both by watching and listening to other's suggestions, and responding likewise as described above. They also used verbal narrations to keep others informed of their own actions and intentions. Furthermore, we found evidence to suggest that features of the tabletop and task design which led to participant's regular 'intrusions' into each other's work may actually have encouraged joint awareness. Tang et al. [19] also found that some accidental interactions around a multi-touch table triggered periods of closer working in pairs of adults working on map-based route planning tasks, and Hornecker [8] found system restraints requiring coordination and sharing of resources, whilst having negative task effects and causing breakdowns, actually fostered cooperation. This could be part of the reason participants generally did not spend large amounts of time working independently of each other although the multi-touch nature of the tabletop theoretically allowed this.

Recent studies suggest that tabletops with multi-touch functionality may not be best for supporting collaborative learning as they allow individual interaction which may not promote joint attention or awareness [6, 7, 14]. Hence, to enable more effective collaborative learning to materialize, it may require techniques such as *enforced* turn-taking and joint-actions to promote joint attention [14]. However, our rich qualitative analysis has allowed us to find things that may be missed by quantitative comparative studies: we found participants *can* manage periods of effective collaboration in terms of learning around a multi-touch table. In turn, these findings can provide insight into how collaborative learning around a multi-touch tabletop may be *encouraged* rather than enforced [2]. For example, they suggest that allowing 'undoing' of other's suggestions may be a way of creating situations for negotiation and encourage task discussion associated with effective collaborative learning. This is in contrast to some current assumptions about the need to have private territories and to restrict access to certain items which has prompted research into the development of mechanisms for mediating access to these [e.g. 12]. Similarly, designing the task to *actually encourage* rather than reduce intrusions (for example by placing icons in places that require reaching over others or necessitating passing) may be beneficial for collaborative learning and encourage joint attention.

CONCLUSIONS AND FUTURE WORK

In this paper we presented and developed the Collaborative Learning Mechanisms framework, based on psychological and learning literatures, for identifying verbal and physical actions and interactions associated with effective collaborative learning. We have used the framework to analyse small group's of children's interaction around a multi-touch tabletop, and in doing so have uncovered how physical and verbal aspects work in parallel as children collaborate. Having unpacked collaboration around the tabletop in this way, we have been able to suggest ways in which collaborative learning around a multi-touch tabletop might be encouraged; in particular we suggest potential value in allowing 'undoing' of other's actions. These insights are in contrast to some current trends in tabletop computing where the intention is not specifically to support collaborative learning, and therefore points to the benefits in using such an approach to understand collaborative learning around tabletop computers in order to better support it.

As we did not compare these findings to other configurations of tabletops (such as one at a time touch, or enforced turn-taking or joint actions), we cannot say these things occurred because of the multi-touch functionality of the tabletop so future research is needed to investigate this. However, in sum, what might be considered undesirable or harmful interactions and intrusions in general collaborative settings – such as grabbing, undoing and blocking – are viewed here as beneficial for collaborative learning, as they trigger further discussion, in terms of elaborations, justification and explication.

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REFERENCES

1. Barbieri, M.S. and Light, P. Interaction, gender and performance on a computer-based problem solving task. *Learning and instruction 2,* (1992), 199-213.
2. Benford, S., Bederson, B.B., Akesson, K., Bayon, V., Druin, A., Hansson, P., Hourcade, J.P., Ingram, R., Neale, H., O'Malley, C., Simsarian, K.T., Stanton, D., Sundblad, Y., and Taxen, G. Designing storytelling technologies to encouraging collaboration between young children. *Proc. CHI 2000*, ACM (2000), 556-563.
3. Block, F., Gutwin, C., Haller, M., Gellersen, H., and Billinghurst, M. Pen and paper techniques for physical customisation of tabletop interfaces. In *Proc. TABLETOP 2008*, IEEE (2008), 17-24.
4. Cappelletti, A., Gelmini, G., Pianesi, F., Rossi, F., and Zancanaro, M. Enforcing cooperative storytelling: first studies. In *Proc. ICALT2004*, IEEE Computer Society (2004), 281-285.
5. Dillenbourg, P., *What do you mean by 'collaborative learning'?*, in *Collaborative learning: Cognitive and computational approaches*, P. Dillenbourg, Editor. 1999, Elsevier: Oxford. p. 1-19.
6. Do-Lenh, S., Kaplan, F., and Dillenbourg, P. Paper-based concept map: the effects of tabletop on an expressive collaborative learning task. In *Proc. HCI 2009*, ACM (2009)
7. Harris, A., Rick, J., Bonnett, V.J., Yuill, N., Fleck, R., Marshall, P., and Rogers, Y. Around the table: Are multiple-touch surfaces better than single-touch for children's collaborative interactions. In *Proc. CSCL09*, (2009), 335-344.
8. Hornecker, E. A Design Theme for Tangible Interaction: Embodied Facilitation. In *ECSCW 2005*, Kluwer Academic Publishers (2005), 23-43.
9. Kruger, A.C. Gender, group composition and peer interaction in computer-based co-operative learning. *Social Development 2* (1993), 165-182.
10. Marshall, P., Fleck, R., Harris, A., Rick, J., Hornecker, E., Rogers, Y., Yuill, N., and Dalton, N.S. Fighting for control: children's embodied interactions when using physical and digital representations. In *Proc. CHI 2009*, ACM (2009), 2149-2152.
11. Mercer, N. and Wegerif, R., *Is 'exploratory talk' productive talk?*, in *Learning with computers: Analysing productive interaction*, K. Littleton and P. Light, Editors. 1998, Routledge: London. p. 79-101.
12. Pinelle, D., Barjawi, M., Nacenta, M., and Mandryk, R. An evaluation of coordination techniques for protecting objects and territories in tabletop groupware. In *Proc. CHI 2009*, ACM (2009), 2129-2138.
13. Pinelle, D., Gutwin, C., and Greenberg, S. Task analysis for groupware usability evaluation: Modelling shared-workspace tasks with the mechanics of collaboration. *ACM Trans. Comput.-Hum. Interact. 10, 4* (2003), 281-311.
14. Piper, A.M. and Hollan, J.D. Tabletop displays for small group study: affordances of paper and digital materials. In *Proc. CHI 2009*, ACM (2009), 1227-1236.
15. Piper, A.M., O'Brien, E., Morris, M.R., and Winograd, T. SIDES: a cooperative tabletop computer game for social skills development. In *Proc. CSCW 2006*, ACM (2006), 1-10.
16. Rick, J., Harris, A., Marshall, P., Fleck, R., Yuill, N., and Rogers, Y. Children designing together on a multi-touch tabletop: An analysis of spatial orientation and user interactions. In *Proc. IDC '09*, (2009), 106-114.
17. Rogers, Y., Lim, Y., Hazelwood, W., and Marshall, P. Equal Opportunities: Do shareable interfaces promote more group participation than single user displays? *Human-Computer Interaction 24, 2* (2009), 79-116.
18. Roschelle, J. and Teasley, S.D., *The construction of shared knowled in collaborative problem solving*, in *Computer supported collaborative learning*, C. O'Malley, Editor. 1995, Springer: Berlin. p. 69-97.
19. Tang, A., Tory, M., Po, B., Neumann, P., and Carpendale, S. Collaborative coupling over tabletop displays. In *Proc. CHI 2006*, ACM (2006), 1181-1190.
20. Teasley, S.D. and Roschelle, J., *Constructing a joint problem space: the computer as a tool for sharing knowledge*, in *Computers as cognitive tools*, S.P. Lajoie and S.J. Derry, Editors. 1993, Erlbaum: Hillsdale p. 229-258.
21. Tse, E., Greenberg, S., Shen, C., and Forlines, C. Multimodal multiplayer tabletop gaming. *Comput. Entertain. 5, 2* (2007), 12.
22. Underwood, J. and Underwood, G., *Task effects on co-operative and collaborative learning with computers*, in *Learning with computers: Analysing productive interaction*, K. Littleton and P. Light, Editors. 1998, Routledge: London. p. 10-23.
23. Weiss, M., Wagner, J., Jansen, Y., Jennings, R., Khoshabeh, R., Hollan, J.D., and Borchers, J. SLAP widgets: bridging the gap between virtual and physical controls on tabletops. In *Proc. CHI 2009*, ACM (2009), 481-490