Measuring 'Framing' Differences of Single-Mouse and Tangible Inputs on Patterns of Collaborative Learning

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Abstract: Research on usability of tangible interfaces has predominantly focused on the *quantity* of interactions. In contrast, we argue that research on tangible and touchable interfaces must focus on the *quality* of interactions. We introduce the concept of *framing and resource activation* in studying the nature of the collaborative activity within tangible interfaces. We observed 40 five year-old children engaging in a math-series activity with either a tangible or single-mouse input, and uncovered four categories of behavioral clusters which accounted for 90% of student interactions. We found a positive correlation between exploratory talk and synchrony cluster (i.e., shared responsibility over the action) particularly on the single-mouse condition, and a negative correlation with passiveness/individual behavior (no negotiation of the actions), predominantly on the tangible condition. This suggests a tension for designers as they aim to balance the learning benefits of focused individual engagement with those that stem from collaboration.

Objectives

Traditional computer interfaces were designed with a single user in mind at a time (Grudin, 1990). However, most of us will agree that today collaboration is an important part for both working and learning. A great deal of research has shown that collaborative learning outperforms individual learning (c.f., Dillenbourg, 1999; O'Malley, 1995). Since the turn of the century, software and interface designers are moving toward facilitation of collaborative interaction in co-located groups (Stahl, Koschmann, & Suthers, 2006). For instance, studies of how people collaborate with multiple-mice inputs, touch surfaces, or tangible interfaces, have received a great deal of attention (e.g., Antle, Bevans, Tanenbaum, Seaborn, & Wang, 2011; Falcão & Price, 2009; Ha, Inkpen, Mandryk, & Whalen, 2006; Harris et al., 2009; Stanton, Neale, & Bayon, 2002). A recent idea of many software and interface designers is to embed features that increase the awareness of participants over each other activities (Dourish & Bellotti, 1992). For instance, Hornecker, Marshall, Dalton, and Rogers (2008) argue that tangible materials increase awareness by facilitating the visualization of activities of other participants.

Research on Human Computer Interaction (HCI) has shown that touchable (or tangible) interfaces can promote equal access (Hornecker et al., 2008), foment on-task talk (Harris et al., 2009), and facilitate simultaneous interaction with the digital information (Harris et al., 2009). In contrast, comparative studies of single-mouse versus multiple-mice inputs have shown that six-year-old children tend to work more collaboratively by having to share a single mouse; conversely, they tend to work in an individual, parallel way with multiple-mice inputs (Stanton et al., 2002; Stanton & Neale, 2003). Thus, there seems to be two competing hypotheses about how single- or multiple-input interfaces support collaborative learning (c.f. Harris et al., 2009). On the one hand, single-mouse allows more discussion at the interior of the group, and allows more awareness of each other's actions by forcing allocation of responsibility (Stanton & Neale, 2003); but it is prone to dominance of one individual over the others, and it has been shown that the talk content is mostly about turn-taking (Harris et al., 2009). On the other hand, touchable or tangible interfaces allow more equity to take place in the physical activity (Rick et al., 2009; Stanton et al., 2002), allow more awareness by visualizing each other's actions (Antle et al., 2011; Ha et al., 2006), and also the talk content is more task-focused (Harris et al., 2009); though, more interferences might occur (Hornecker et al., 2008).

However, the epistemological assumptions of how tangible designs might enhance collaboration must be explicitly addressed (Dillenbourg, 1999). This mixed evidence from previous research creates a paradox: Are people inherently individualistic so that we ought to design interfaces in such a way that users are forced to collaborate, or do people have a natural inclination to collaborate but traditional interfaces prevent them from doing so? Additionally, does traditional technology, designed with only a single user in mind facilitate more collaboration?

The apparent paradox is created by mistakenly identifying where the *locus* of the collaborative activity is situated. We believe that although previous literature on HCI design shows the trend has moved to support group behavior, there is no consensus on the level of the unit of analysis (Dillenbourg, 1999) . This issue causes mixed and contradicted results in the literature on tangibles, tabletops, hybrid surfaces, and other shared-ware technology. In this paper we would like to address this problem by elucidating a possible answer to the question of how to study collaboration on this type of interfaces, i.e., by taking into account a dynamic unit of analysis.

Theoretical and Design Framework

We argue that theory and research on tangible and touchable interfaces has to pay attention to the level of unit of analysis. We are introducing the concept of *framing and resource activation* (Conlin, Gupta, & Hammer, 2010; Scherr & Hammer, 2009) to study the nature and quality of the collaborative activity within tangible and touchable interfaces. Framing has been defined in the anthropological literature as the structure of expectations of how people understand, moment by moment, the character of an activity; stated more simply, a sense of 'what is going on' (Tannen, 1993). Also, Conlin et al. (2010) introduce the idea of ontological frames as a coherent activation pattern of resources. These authors state that framing has a dynamic nature, in which the pattern of activation involves manifold resources, whether in the individual mind, across minds, or across minds and materials. Some studies of these ontological framings have pointed out that various behaviors tend to cluster together both within and across participants of an activity. Also, there seems to be only so many behavioral clusters that can account for most of the time participants interact with each other. Moreover, Conlin et al. (2010) found that one of these clusters tends to be specially correlated to a particular type of reasoning, e.g., scientific reasoning.

We intend to use this framework of framing and resource activation to first categorize the clusters of behavior in a particular activity with either tangibles or single-mouse input, and second, to correlate one of these clusters with a type of productive talk, called 'exploratory talk' (Mercer, 2008). Exploratory talk has been defined as "the active joint engagement of the children with one another's ideas." (Littleton et al., 2005, p. 5). That is, we wanted to study whether children would frame the activity to collaborate and negotiate meaning, or as an independent, parallel work.

In order to understand how this dynamic unit of analysis informs collaborative learning in tangible environments, we examined how children collaboratively worked to solve a problem of mathematical series by using either a single-mouse or tangible objects. However, we were more interested in the process of how children learned within this collaborative activity than in the product of such an activity, a method that other authors have proposed (c.f., Dillenbourg, Baker, Blaye, & O'Malley, 1996). This is one way we might better inform the design of such tangible interfaces.

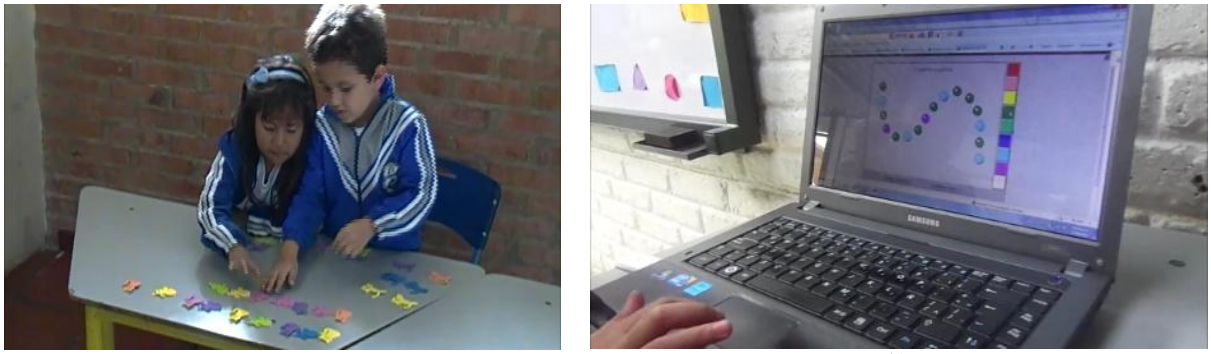
Methods

Participants were 40 five-year-old kindergarten students from a public school in a capital city in South America. A between-subjects condition was employed in which we randomly assigned half of the students to a single-mouse condition and the other half to a tangible condition. We considered the mouse interface condition as a type of single-input activity, whereas the tangible condition as a type of multiple-input. For the tangible condition, children were given plastic objects (e.g. geometric figures, animal figurines, colored beads). For the mouse condition, children used virtual manipulatives available on-line at the National Library of Manipulatives (Dorward & Heal, 1999). We let students use the touchpad at the center of the laptop instead of the physical device, for it was equidistant to each participant. Many teachers use this kind of settings in which they have students work in pairs with tangible material or virtual manipulatives on a laptop that is shared by a couple of students (Rosen & Hoffman, 2009). In future studies newer technology, such as iPad's, can be used rather than laptops. In the present study, iPad's were not used due to limited funds.

Four tasks on mathematical series were presented to the dyads to solve together. A series task is a common mathematical activity that children solve with manipulative objects, such as geometric figures or colored objects of different sizes. In a word, a series task is an activity of finding a pattern (by shape, color, size or more than one feature) that repeats throughout a long sequence of objects. This task has also been popular with the use of virtual manipulatives, which makes it a suitable task for a comparison between a tangible-environment against a single-mouse interface. Also, such an activity is both engaging and demanding for children of this age. Further, we expected this activity would help children engage in a discussion that challenges their knowledge about mathematical relationships. The first task was to create a necklace with color beads; the second task was to create a sequence of animals; the third task was to create a sequence of colored beads with two levels ABAB or ABCABC (see figure 1); the fourth task was to complete a sequence of geometric blocks.

Students were paired up by the teacher in a way that she believed created dyads that would interact well. The pairs were balanced to include a similar number of same and mixed gender compositions. The task was conducted in a separate classroom with one dyad at a time in order to have a better setting to capture good quality video-recordings. No explicit roles were assigned or explicit instructions given on how children were to deal with turn-taking. Instructions were simple and given by the researcher (e.g., "You are to discover a pattern shown by the first elements in the sequence and then follow it"). Before the four tasks started, children were given some time to familiarize with the materials. We used this initial game as an activity to informally test children's ability to manipulate the concrete materials or the touchpad. Although all the activities were considered for the initial steps at the qualitative analysis and interpretation, for the purpose of this paper we analyzed the third task in a fine-grain detail, in which the type of material was the most similar in both

conditions. This activity lasted about 2-3 minutes for each pair, and the four activities went on for about 15 minutes in total.



a) b)

Figure 1. Two conditions of a math series task; a) tangible objects, and b) virtual manipulatives

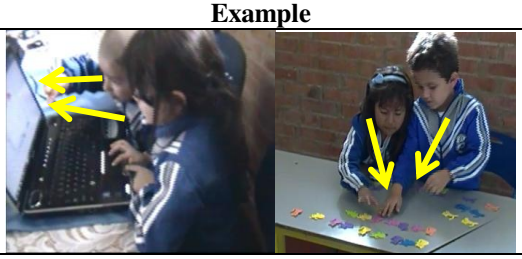
Measures of Behavior

We developed a coding scheme to capture clusters of behavior. This coding scheme was partially based on Conlin et al. (2010) and was aligned with Collazos et al. (2007) idea of *synchrony of collaboration*. A synchronous activity can be understood as a 'meta-cognitive' contract in which both participants expect their messages be processed fluidly and misunderstandings resolved (Collazos & Mendoza, 2006). We delimited a span of 10 seconds as a time long enough as to include sufficient information to determine how children's behavior converge on a certain cluster; and also short enough as to have enough number of total clusters throughout the activity. Six major categories were conceived: synchrony, interference, passiveness, individuality, distraction, and indeterminate (see Table 1). However, because of the particularities in each condition (there is no individual-parallel work on single-mouse condition) the categories of passiveness and individuality were collapsed into one single code (passive is "like" doing things on your own, without paying much attention to the group-mate). Scores on these categories represent proportion of behavior occurrence (each one 10 seconds long). Two researchers independently coded all the videos for activity three and then met to resolve differences until a 100% agreement was reached.

Measures of Talk

We also transcribed children's talk and non-verbal language. We developed a coding scheme to categorize their talk to sort out level of engagement when negotiating a shared understanding throughout the problem-solving activity. This coding scheme was partially based on the concept of exploratory talk developed by Littleton et al. (2005). The rest of the scheme was based on a converging process of refining interpretations from several iterations of watching the videos and discussing them within the research group. Four major categories were conceived: exploratory, narrative, disputative, and other (off-task). Scores on these categories represent proportion of utterances. Each category was subdivided in various sub-codes (see Table 2). Two researchers coded half of the transcripts and a third researcher coded an overlapping 50%. Overall inter-rater agreement was 87%.

Table 1: Categories of Behavioral Clusters

Category	Description	Example
Synchronous	• Participants share the focus of attention and their gaze is directed towards the same point. • Their actions contribute to the result of the activity. • They implicitly share responsibility for the action.	

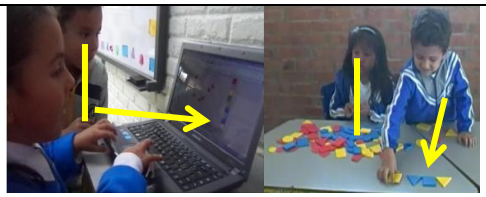
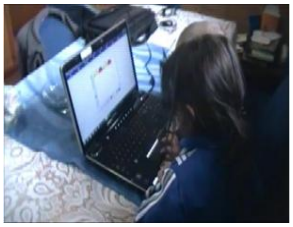
Passive	• Participants may or may not share the focus of attention. • However, the authorship of the action is not shared, because the activity is not the result of the joint action of the participants.	
Individuality	• Participants, despite having active roles, act independently, without actually articulating or negotiating their actions.	
Interference	• Participants may or may not share the focus of attention. • However, the action of a member hinders the action of the other.	
Distraction	• The focus of the participants does not coincide with that of the proposed activity. • Participants are distracted and look to a different place.	
Indeterminate	• There is ambiguity about the actions of the participants. • Unable to determine with certainty the intent or purpose of the action. • Includes technical, incidental, and accidental circumstances that prevent determining with certainty the purpose of the action. • The category also serves to code actions that are not relevant to this investigation (jumping for joy, singing, dancing, etc.).	

Table 2: Categories for utterance codes

Category	Sub-code	Example
Exploratory In these types of statements the intention is to construct meaning. In a way, participants intend to make a 'shared reasoning' about the problem and its solution.	Propose or suggestion	"All we need is a pink." "We have to remove this." "Put it below the other." "You are to do this." "Put it here."
	Inquiry	"What?" "How?" "Where to?" "What is this?" "Blue?" "Here?"
	Respond	Boy: "Do I do it?" Girl: "Yes, do it."
	Explain	"If there are two reds here, if you put two red ... here are two yellow, two yellow, two red, two red."
Descriptive Such utterances are primarily intended to narrate the facts,	Egocentric narrative	"This goes here," "here we go again," "we're almost there."
	Passive narrative	"Hey, you need to put three here!"

events or intentions of participating subjects. It is not the intention to anticipate what needs to be done.	Description	"Here's one, two, three." "All the colors are gone." "White is there already."
	Assertion	"That's it," "It is this one," "I do mine," "Here!"
Disputative These types of statements show a lack of agreement among the participants, either because they do not agree, because they do not know how to fix the activity, or because they do not like how the other is acting.	Negative	"No, not here!"
	Push back	"Let me do it!" "I do it 'cause I know how to!" "Help me!" "You do it!"
	Demand	"Why did you do that?" "Now it broke!" "You don't want to play with me." "Don't do it so hard." "Don't do that!"
Others: This category includes utterances that are not addressed explicitly or implicitly to the solution of the problem or support the interaction of participants to solve the problem.	Others	"I'm thinking I'm good at this," "I scraped myself".

Results

Finding Patterns of Behavior and Talk

All dyads completed the task correctly, and took on average about two minutes to solve it (M=2:14, SD=1:27). Participants in the virtual condition (M=2:42, SD=1:53) took longer than the tangible condition (M=1:47, SD=0:27). In general, in the tangible condition children did not talk as much (151 utterances total), and talked in an egocentric way (narrative talk). It seems they were narrating and describing what they were doing, instead of collaboratively planning future moves (see Table 3). In fact, they only included a low percentage of exploratory utterances. On a positive note, though, they were not involved in as many moments of conflict (disputative talk) as on the single-mouse condition. Nonetheless, the tangible condition seems to have elicited more independent work in the form of two parallel, individual activities (see Table 4). For instance, it is apparent from the following excerpt of the tangible condition that both children were motivated on solving the problem, but this behavior seemed more like a parallel attempt without many purposeful exchanges of negotiation.

Group1: tangibles (dyad 3)

(Child A begins to place chips on the table while B notices it)
Child B: *I will put this one.* (Child B puts one chip while Child A keeps placing other chips) *Oh! I got this one.*
Child B: (Child B places the remaining chips and Child A looks elsewhere). *Here, look.*
Child A: *This one goes here.*
Child B: *This one. Done!* (End of activity).

Table 3: Percentage of utterances by condition.

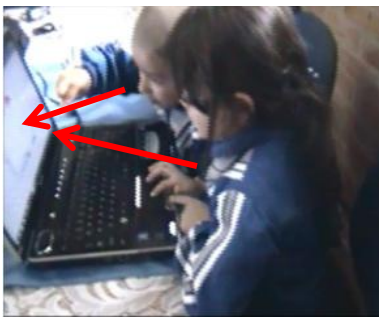
	Exploratory	Narrative	Disputative	Others	Total
Tangible	23 (15.23%)	**84 (55.63%)**	14 (9.27%)	30 (19.87%)	151 (100%)
Single-mouse	**130 (44.52%)**	69 (23.63%)	**64 (21.92%)**	29 (9.93%)	292 (100%)

Table 4: Percentage of behavioral clusters by condition.

	Synchronous	Passive/ Individual	Interference	Distraction	Indeterminate	Total
Tangible	12 (11.54%)	**70 (67.31%)**	8 (7.69%)	5 (4.81%)	9 (8.65%)	104 (100%)
Single-mouse	**103 (68.21%)**	23 (15.23%)	5 (3.31%)	5 (3.31%)	15 (9.93%)	151 (100%)

On the other hand, single-mouse interaction led to a greater number of utterances (292 total). Children talked about future moves, planning, proposing, asking and explaining, which we labeled as 'exploratory talk'. Children also talked about turn-taking, but this talk was not as frequent as previous research suggests (Harris et al., 2009); in fact, only 18 over a total of 130 exploratory utterances were coded as turn-taking (7.22%). Children in this condition also talked egocentrically, which was observed about half the time compared to the tangible condition. However, children did tend to argue more and conflicts arose from time to time. Indeed, children on the single-mouse condition tended to exchange a sustained, vivid dialog to keep the activity going on. For instance, in the following excerpt, not only did these kids maintain a dialog prominent with inquiry, explanations and suggestions, but also with a small level of strain:

Group2: single-mouse (dyad 1)



Boy: *Your turn.*
(Girl manipulates the mouse)
Boy: *And there's a red... Two red ... you're doing it wrong*
(Girl continues to manipulate the mouse, while he seems focused on what she does)
Boy: *Girl, here I think two reds should follow* (points on the screen with two fingers)
(Girl silently manipulate the mouse and completes the two colors)
Boy: *No, not there ... here.*
Girl: *I know!*
Boy: *Then delete them ... those two* (scratches his head)
Girl: *But they have to be pink and have to be here.*
(Boy cautiously takes off his hand from the mouse and then points at the screen)
Boy: *Here you are missing a red, two red, look* (manipulates the mouse) *here... I'll take this, this, this, this and this* (deletes them, trying to correct some colors)
Girl: *your turn* (ceding the control of the mouse)

Correlations between Behavior and Talk

In order to understand if there were systematic differences on behavioral clusters and talk between single-mouse and tangible conditions, a one-way MANOVA with three categories of talk and four categories of behavior was conducted. With the use of Wilk's lambda criterion, the combination of these observed measures was significantly related to the condition ($F(7,12)=4.91$, $p=.008$), with a large magnitude of association ($\eta^2 = .741$). A series of univariate ANOVA tests with alpha = (.05/7) was performed to find significant differences on the dependent measures. We found that *exploratory talk* was significantly higher for single-mouse condition (M=12.9, SD=8.0) than for tangible condition (M=2.30, SD=1.77), $F(1,18)=16.71$, $p=.001$, with a large effect of association, $\eta^2 = .481$. *Passive/individual behavior* was significantly higher in the tangible condition (M=7.0, SD=3.29) than in the single-mouse condition, (M=2.0, SD=2.01), $F(1,18)=16.30$, $p=.001$, with a large effect of association, $\eta^2= .475$. *Disputative talk* was marginally higher in the single-mouse condition (M=6.20, SD=6.75) over tangible condition (M=1.40, SD=2.01), $F(1,18)=4.65$, $p=.045$, with a medium effect of association, $\eta^2= .205$. Also, *synchronous behavior* was marginally higher on single-mouse condition (M=10.20, SD=10.79) over tangible condition (M=1.20, SD=1.23), $F(1,18)=6.86$, $p=.017$, with a medium effect of association, $\eta^2= .276$. We also found that *exploratory talk* was highly correlated with *synchronous behavior* ($r=.852$, $p<.001$), and with *disputative talk* ($r=.651$, $p=.001$, $R^2=.423$), and also negatively correlated with *passive/individual behavior* ($r= -.583$, $p=.007$, $R^2=.339$).

Our results provide evidence to support Stanton et al.'s (2002, 2003) hypothesis. Single-mouse interfaces for these particular tasks seem to promote more dialog, discussions and more arguments among participants. Furthermore, this kind of talk was highly correlated to a set of behaviors that imply synchrony in which both participants processed each other's messages and resolved misunderstandings fluidly. We also

noticed, as Harris et al. (2009) did, that in the tangible condition children tend to talk more about the task, but it took the form of a parallel activity instead of a collaborative effort. Finally, on the single-mouse condition children did talk more about turn taking, again noticed by Harris et al. (2009), but these conversations only account for less than 10% of the collaborative talk.

Discussion and Conclusion

This paper intends to make a contribution to the literature on evaluation of the usability of tangible interfaces and collaborative learning. Previous research on the usability of tangible interfaces has predominantly focused on the *quantity* of direct interaction (e.g., Fjeld, Schar, Signorello, & Krueger, 2002; Ha et al., 2006; Harris et al., 2009). From our point of view, by introducing the concept of exploratory talk to the study of collaboration within an object-manipulation task, we have been able to sharpen the study of the *content* of the talk this type of interaction elicits. Also to acknowledge that collaboration can occur in performance as well as talking, we measured behavioral clusters of physical actions from a framing perspective. Through this process, we have paid much closer attention to the *quality* of the interactions than previous studies have.

By using this framework of framing and resource activation, we found four categories of behavioral clusters in the math-series activity, either with tangibles or single-mouse input. These four clusters (synchrony, interference, passiveness/individuality, and distraction) accounted for more than 90% of students' interactions during the problem-solving activity. We also found a large positive correlation of exploratory talk with the synchrony cluster, particularly for the single-mouse condition. At the same time, we found that exploratory talk was negatively correlated with passiveness/individual behavior, which was predominant in the tangible condition.

What does it all mean for collaboration and learning? For collaboration this suggests that if the unit of analysis is at the level of the dyad, participants are more engaged in talk and negotiation by having to share the object of interaction. From a social-mind-unit-of-analysis perspective, it seems plausible to understand that the nature of a collective activity is directed by a shared object (literally, in this case). This shared object then shapes individual actions and other mediators within the shared activity (Engeström, 1987). On the other hand, conclusions for learning might not be as straightforward, because the narrative talk that we observed with tangible materials was a particular type of egocentric talk which is characteristic of this range of age. However, Vygotsky (1986) was one of the first psychologists to notice that egocentric talk might in fact be beneficial to the child's cognitive development. In this way, at the individual level of analysis it seems that tangible objects engage students and challenge their mathematical knowledge. Although this kind of egocentric talk is important for the child's reasoning, as Vygotsky noticed, it is not shared or negotiated synchronically with others at this developmental point yet. This suggests a tension for designers of tangible interfaces as they aim to balance the learning benefits of focused individual engagement with those that stem from collaboration. We believe that recognizing how participants tend toward a set of behavioral clusters during their interactions, and then understanding how this set of clusters correlate with a particular, desired reasoning process is an important step for evaluating the shareability of every interface.

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