Towards Seamless Support of Natural Collaborative Interactions

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Abstract

In order to effectively support collaboration it is important that computer technology seamlessly support users' natural interactions instead of inhibiting or constraining the collaborative process. The research presented in this paper examines the *human-human* component of computer supported cooperative work and how the design of technology can impact how people work together. In particular, this study examined children's natural interactions when working in a physical medium compared to two computer-based environments (a traditional desktop computer and a system augmented to provide each user with a mouse and a cursor). Results of this research demonstrate that given the opportunity, children will take advantage of the ability to interact concurrently. In addition, users' verbal interactions and performance can be constrained when they are forced to interact sequentially, as in the traditional computer setup. Supporting concurrent interactions with multiple input devices is a first step towards developing effective collaborative environments that support users' natural collaborative interactions.

Key words: Computer supported cooperative work (CSCW), computer supported collaborative learning (CSCL), single display groupware (SDG), user interfaces, multiple mice, and synchronous interaction.

1 Introduction

Collaboration with colleagues, friends, and/or classmates is often an important part of our daily activities. Whether working together to write a paper, brainstorming a software engineering design, consulting on a medical diagnosis, or for the enjoyment of playing with others, we often need or want to be able to collaborate with others. When these activities require the use of computer technology, we are limited by the underlying one-person/one-computer paradigm of typical computers found in homes, schools and workplaces. Existing alternatives include working together on networked workstations (presuming that collaborative support has been facilitated through software) or gathering around a single workstation. The research presented in this paper explores ways to more effectively support natural collaborative interactions of people working together in small, co-located groups. Specifically, this work addresses the importance of providing multiple input devices to support multiple concurrent interactions and the impact this has on the effectiveness of the collaboration.

An investigation was undertaken into the behaviours of school-aged children performing a puzzle-solving task under different experimental conditions: (1) a physical paper-based condition; (2) a one-mouse one-cursor condition; and (3) a two-mice two-cursor condition, that allows for synchronous independent interactions. It is important to explore issues of collaboration for the domain of education given that many traditional classroom activities utilize computers. These environments must support the strong social interactions both within groups of students and between students and teachers. It is essential that the natural collaborative interactions that exist for traditional learning settings be supported in modern computer-based learning environments. This will help ensure that the benefits associated with this rich form of interaction are not lost. Computer technology should support, and not interfere with, users' natural collaborative tendencies.

This paper presents a review of related research in Section 2, followed by a discussion of the methodology in Section 3. Section 4 reports on preliminary results gathered from this work, published previously, and Section 5 presents more in-depth analysis of the results. Section 6 provides an overall discussion relating to the underlying goals of this research. Finally, in Section 7, conclusions are presented as well as implications on future research in this area.

2 Related Work

It is becoming apparent that the conventional computer does not support some desired types of collaborative activities. To deal with this, many researchers are exploring alternative technologies to improve support for collaboration.

2.1 Alternative Collaborative Technologies

One approach to the support of collaborative activities is the development of alternative technologies based on real-world artifacts that facilitate collaborative interactions. This approach combines existing collaborative tools from the physical world (e.g. a whiteboard), with the benefits of traditional computer technology. Interactive displays, such as electronic whiteboards [9, 13] and tabletop displays [14], are two alternative technologies based on real-world counterparts.

Electronic whiteboards and tabletop displays are natural choices since they are based on a shared surface metaphor, such as a typical office whiteboard or a table surface. This allows researchers to take advantage of the fact the most users are familiar with collaborating around whiteboards and tables. More importantly, these metaphors facilitate collaboration by providing surfaces large enough for multiple people to collaborate around without crowding, allowing unrestricted drawing and erasing that is essential for many informal collaborative tasks, and giving all group members access to the shared workspace [13].

2.2 Alternative Interaction Devices

Beyond display, the design of input devices and interaction styles can also help support natural collaborative interactions. Researchers have begun to look at alternative input devices that support computer interaction through the manipulation of physical objects.

LEGO/Logo [10] was an early system that utilized physical manipulation of programmable blocks in a collaborative process. With this system, children could write programs using the Logo programming language, allowing them to control machines that they built with LEGO toy construction pieces. This system, though, required an intermediate interaction involving a traditional computer to perform the Logo programming before the LEGO pieces became interactive.

Tangible user interfaces (TUIs) [4] is a research area that investigates the manipulation of physical objects to interact with computers and can be a means of supporting face-to-face collaboration. Tangible user interfaces take advantage of the fact that physical objects naturally afford certain interactions [4]. These affordances help make the interfaces more intuitive to interact with than indirect manipulation devices such as a mouse. Manipulating TUIs requires body movement and body positioning within a physical space which provides a rich source of non-verbal communication to help manage the collaborative process [15]. For example, in a user study utilizing AlgoBlocks[1], it was found that a user's body movement, such as picking up a block, focused the attention of the user, drew the attention of the other group members, allowed the group to see the user's intention, and allowed the members of the group to monitor that user's progress.

2.3 Multiple Input Devices

Along with the development of alternative input devices, several researchers have explored the use of multiple input devices to facilitate multi-user interaction. This has been a main research direction in the area Single Display Groupware (SDG), which examines ways to support small groups of people collaborating around a shared display [11]. One of the first SDG systems was the Multi-Device, Multi-User, Multi-Editor (MMM) [1] which allowed up to three mice to be used to synchronously interact with a shared application. Since then, other researchers have investigated the technical issues surrounding support for simultaneous multi-user interaction [2, 3, 8].

Motivation behind the development of technology that supports multi-user interaction stems from previous research that has suggested that supporting co-located collaboration can provide positive achievement and social benefits for children in educational learning environments. Inkpen *et al.* [5] found that children were more motivated to play a commercial problem-solving computer game and were more successful in the game when playing together on a single machine as opposed to playing on side-by-side computers or by themselves. Inkpen *et al.* [7] and Stewart *et al.* [12] have also shown increased achievement and motivational benefits by providing support for multi-user interactions to children collaborating in a computer environment.

3 METHOD[2]

The study involved pairs of children playing a puzzle-solving activity using three different experimental set-ups: (1) a paper-based version of the game with physical pieces; (2) a computer-based version of the game with one mouse and one cursor; and (3) a computer-based version of the game with two mice and two cursors.

3.1 Participants and Setting

The study took place in a public elementary school on the east side of Vancouver, British Columbia, Canada. The school is located in a lower-economic, culturally diverse area of Vancouver. The participants included

[1] AlgoBlocks is a tangible programming language developed as a collaborative learning tool for children [15].

[2] The method presented here was also reported in an earlier paper discussing preliminary results gathered from the study [6].

forty children (22 girls and 18 boys) between the ages of nine and eleven from three grade four and five classes. Parental consent was obtained for all children who participated in the study. The study ran for three consecutive days in April 1999 in a small conference room that was located in the school library. The research area included two experimental setups, each consisting of an IBM-compatible PC, a video camera with two lavaliere microphones to capture the children's interactions, and a scan-converter to capture the computer screen. The two experimental setups were configured back-to-back so children working on one computer could not easily see the other computer.

3.2 Alien pattern game

The puzzle-solving game developed for use in this study involved placing alien faces with varying attributes in a row according to a specific pattern. The alien faces had three possible head colours (blue, green, or red), three possible eye colours (black, green, or red), and two possible mouth styles (happy or sad). Each puzzle began with nine squares positioned in either a horizontal or vertical row with an alien face placed in each of the three center squares. The remaining six alien faces were randomly scattered around the playing screen. The object of the game was to place the remaining six alien faces in the correct squares according to a specific pattern (see Figure 1). Three sets of twenty different patterns were created where each set had the same patterns with only the colour of the attributes changing between each set.

The paper-based version of the game was played on a 14" X 8" sheet of laminated paper (see Figure 2). The alien faces were mounted on 1" X 1" magnets to make them easy to handle. The alien faces were moved into place by physically positioning them on the paper. To check a solution, the players were required to ask a researcher whether or not it was correct. If the pattern was incorrect, the researcher asked the children to keep trying. If the pattern was correct, the researcher provided the children with the next puzzle in the game.

The computer versions of the game were played on IBM-compatible PCs with 14" monitors. The alien faces were moved into place using a mouse. To check a solution, the players were required to click the "check-answer" button located on the top left-hand corner of the screen. If the pattern was incorrect, an error message appeared, asking the children to try again. If the pattern was correct, a congratulation screen appeared and the players advanced onto the next puzzle. The software was developed using C++ and Microsoft DirectX and displayed a different colour cursor for every Universal Serial Bus (USB) mouse attached to the computer.

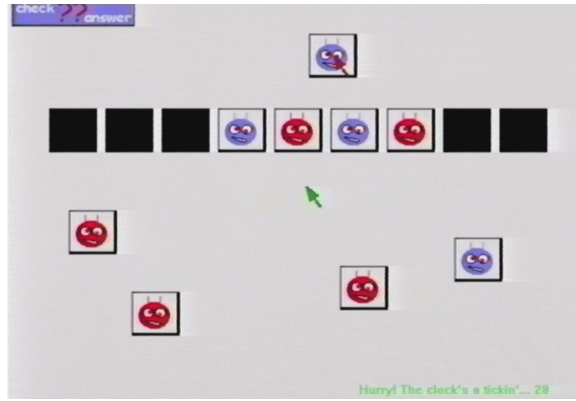

Figure 1. Sample puzzle screen from the computer version of the Alien Pattern game.

Figure 2. A pair of children playing the paper-based version of the Alien Pattern game.

3.3 Experimental Variables

A repeated measures design was used in this study with two independent variables: gender and collaborative condition. Both males and females participated in the study but only same-gender pairs were used. The collaborative conditions included: (1) paper-based; (2) one-mouse/one-cursor; and (3) two-mice/two-cursors. In the paper-based condition, pairs of children played using the paper version of the alien puzzle game. In the one-mouse/one-cursor condition, pairs of children played on a computer with one mouse and one cursor. In the two-mice/two-cursor condition, pairs of children played on a computer with two mice and two cursors. All pairs of children played the paper-based version of the game first and the order of the remaining two conditions was counterbalanced. This allowed all children to become familiar with the game before playing the computer-based version to minimize the effect that learning may have had on the computer-based conditions. It also provided information on how each pair of children interact given a medium that affords multiple users interacting simultaneously.

The dependent variables analyzed included engagement, activity, concurrent interaction, verbal discussion, and puzzle duration. Engagement was measured by the amount of off-task behaviour exhibited by the children, gathered through video analysis. Activity was measured by the number of actions performed by each partner and by the pair as a whole, collected through computer logs and video analysis. These results were reported in an earlier paper on this study [6]. The amount of concurrent interaction was gathered through video analysis for the paper condition and through computer logs for the two computer-based conditions. For each pair, three categories of activity were recorded: (1) the amount of time both children were active (i.e. holding/placing pieces in the game); (2) the amount of time one of the partners was active (i.e. only one of the children holding/placing pieces in the game); and (3) the amount of time neither partner was interacting with the game. Verbal discussion was analyzed, for each user, through video analysis, recording the amount of on-task discussion initiated with his/her partner. Puzzle duration was the length of time it took the pairs of children to solve each puzzle in each of the experimental condition. Other data gathered included background information for the children, a post-session questionnaire, and qualitative observations gathered through video analysis.

3.4 Procedure

The children were randomly assigned a partner of the same gender from their class. Two pairs of children at a time were excused from regular class activities for one hour to take part in the study. The study began with welcoming remarks from the researchers, followed by the children filling out a short background questionnaire. The paper-based alien game was then described to the children and they were asked to play the game for ten minutes. All children played the same set of puzzles in the paper-based version. Following this, the children were told that they would be playing the same game two more times using a computer. It was explained that one computer had two mice while the other computer had one mouse, and that it was up to the children to decide how they would coordinate their play. In the one-mouse/one-cursor condition, the pair of children were free to share control of the mouse as they wished. One pair of children was randomly selected to begin with the one-mouse/one-cursor setup while the other pair began with the two-mice/two-cursors setup. A random assignment procedure was also used to select which puzzle set each pair would use in their first computer condition (out of two possible sets). The children were allowed to play for ten minutes. After the ten-minute session, the pairs of children switched computers and played the game for another ten minutes using the alternate collaborative setup and puzzle set. Following the last experimental condition, the children filled out a post-session questionnaire and engaged in casual discussion with the researchers before returning to class.

4 Preliminary Results

Preliminary qualitative and quantitative analyses from the study described in this paper were previously reported [6]. These results revealed three main benefits of providing multi-user interaction to the children. First, the children exhibited a significantly higher level of engagement when allowed to synchronously interact with the computer. Second, the children tended to be more active when multi-user interaction was supported. Finally, the children significantly preferred playing on a computer that supported concurrent multi-user interaction.

5 Results

This paper presents an in-depth analysis of users' concurrent interactions, verbal communications, and performance, and how these variables differed across the three experimental conditions.

5.1 Concurrent Activity

One of the benefits provided by the physical world is the ability that people have to interact simultaneously. The issue of concurrent interaction was explored by examining how often people chose to work simultaneously when completing a collaborative task. Data was gathered from 14 pairs of children[3] on the amount of time users interacted concurrently (i.e. both players active at the same time), the amount of time users interacted sequentially (i.e. only one player active), as well the amount of time when neither partner was active. The results for the three experimental conditions are shown in Table 1. Figure 3 shows three segments from the video annotation system timeline that illustrates the concurrent nature of interactions in the paper condition and the two-mice condition, compared to the forced sequential interactions in the one-mouse condition.

Not surprisingly, in the paper condition, users were frequently active at the same time (37.5% of the time). This tangible medium, combined with the fact that the puzzles had several distinct physical pieces, enabled users to hold/place pieces simultaneously if desired. In the two mice condition, users also exhibited a high

[3] Data is only available for 14 of the 20 pairs of children, due to problems with video quality.

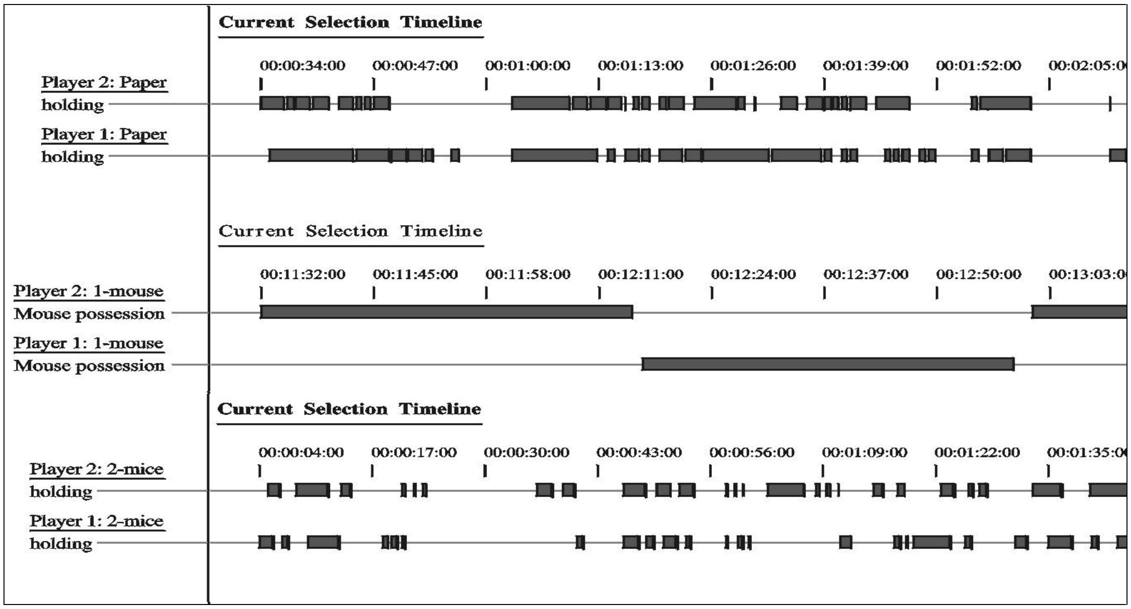

Figure 3. Three segments from an activity timeline illustrating when each user is holding and/or placing an object in the game, for the paper and two-mice conditions, and mouse possession for the one-mouse condition.

degree of concurrency, with simultaneous interactions 27% of the time. In this condition, providing each user with an input device and cursor enabled both children to interact with the game simultaneously, when desired. In contrast to the paper and the two-mice conditions, the one-mouse condition did not support simultaneous interaction. Therefore, users were forced to interact sequentially, taking turns with the mouse. Users tended to resist surrendering the mouse to their partners, even during idle periods. As a result of this behaviour, there was a significantly larger amount of time when neither partner was active than compared to the paper and two-mice conditions, $F(1,13) = 54.35$, $p<.05$ and $F(1,13) = 67.67$, $p<.05$ respectively.

Table 1. Average length of time both players were active (concurrent interaction), one player was active (sequential interaction), or neither player was active. Note, the total session time was 600 seconds.

	n (pairs)	Concurrent Interaction	Sequential Interaction	No Activity
Paper	14	225 sec. (37.5%)	102 sec. (17%)	273 sec. (35.5%)
One-Mouse	14	0 sec. (0%)	225 sec. (37.5%)	375 sec. (62.5%)
Two-Mice	14	162 sec. (27%)	214 sec. (36%)	224 sec. (37%)

It is important to recognize that interacting directly with the game via an input device is only one aspect of a user's "activity". In the one-mouse condition, the children performed both verbal and physical actions to provide input when not in control of the mouse. For example, each pair of children was observed physically pointing to the screen an average of 15.6 times per session in the one-mouse condition[4]. This was significantly more than the average 2.6 times in the two-mice condition, $F(1,19) = 27.38$, $p<.05$, however, pointing with the mouse cursor was not recorded in either computer conditions. Physical pointing in the paper version was comparable to the one-mouse condition, with an average of 12.2 times per session, $F(1,19) = 1.85$, *ns*. Children may have also remained active by issuing verbal instructions to their partner. In the one-mouse condition, this occurred an average of 3.75 times for each child per session, although this number was not statistically different from the number of instructions issued during the two-mice condition, $F(1,23) = .553$, *ns*.

5.2 Verbal Interactions

The amount of verbal interaction between participants was measured to gain insight into the impact each experimental condition had on collaborative dialogue. The amount of on-task verbal communication per user was

[4] Data from all 20 pairs of children was used for this analysis.

recorded for twelve of the twenty pairs of children[5], for each of the three experimental conditions and is shown in Table 2. A statistically significant difference was observed for experimental condition, $F(1,20) = 5.19$, $p<.05$. The two between-subject factors, gender and first computer condition, also produced marginally significant results, $F(1,20) = 4.35$, $p=.05$ and $F(1,20) = 3.413$, $p=.08$, respectively.

Table 2. Mean number of times users engaged in on-task discussion with his/her partner for each of the three experimental conditions.

		n (children)	On-Task Discussion
Paper Condition	Girls	16	17.25
	Boys	8	34.13
	Total	**24**	**22.88**
1-Mouse Condition	Girls	16	26.38
	Boys	8	36.00
	Total	**24**	**29.58**
2-Mouse Condition	Girls	16	27.38
	Boys	8	42.50
	Total	**24**	**32.42**

Figure 4 illustrates the average number of verbal communication events, per user for each experimental condition, based on which computer condition they played first. This result is interesting given the significant interaction effect uncovered in the preliminary results of this work [6][6], as illustrated in Figure 5. In both cases, playing the one-mouse condition first resulted in an increase (in number of actions and verbal events between players) when playing the follow-up two-mice condition. In contrast, playing the two-mice condition first caused no such increase (in number of actions and verbal events between players) in the follow-up one-mouse condition.

5.3 Puzzle Duration

A third measure of effective collaboration is related to the pairs' ability to solve puzzles in the game. The length of time the users took to solve each puzzle for each collaboration condition was recorded[7]. A marginally significant interaction effect for the first computer

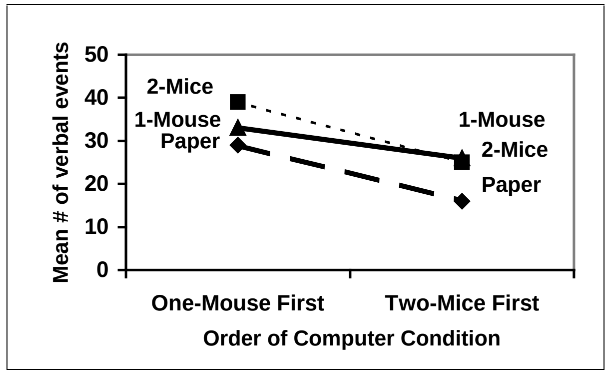

Figure 4. Mean number of verbal communication events for each user, in each condition, categorized by which computer condition they played first.

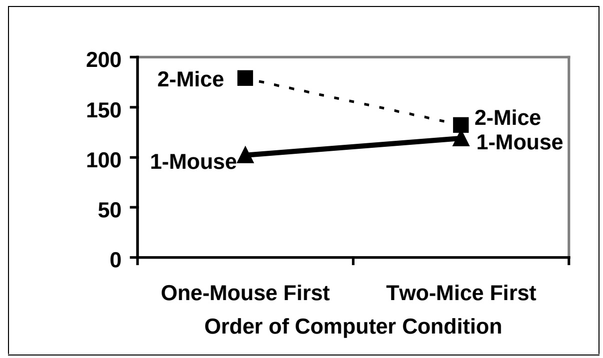

Figure 5. Mean number of actions (placing pieces or clicking on the guess answer button) for each user, in the two computer conditions, grouped by which computer condition the users played first.

condition was found, $F(1,17) = 4.280$, $p=.054$. As a result, the data was analyzed separately for each starting computer condition. Figure 6 shows the average length of time to complete puzzles in each of the experimental conditions. For each user pair, only puzzles that were completed in all three conditions were included in this analysis. For users who played the one-mouse condition first, a marginally significant improvement in times to complete puzzles was found when they played in the subsequent two-mice condition, $F(1,7) = 5.404$, $p=.053$. This improvement may have been related to the users' increase in activity and/or increase in verbal communication as reported in the previous section. For users who played the two-mice condition first, no such improvement was found in the subsequent one-mouse condition, $F(1,10) = 0.14$, *ns*.

[5] Data is only available for 12 of the 20 pairs of children, due to time constraints and problems with video quality.

[6] [6] reported an interaction effect between the average number of actions exhibited by each user in the one-mouse and two-mice condition, and which of these conditions they played first.

[7] Data is only available for 19 of the 20 pairs of children, due to problems with video quality.

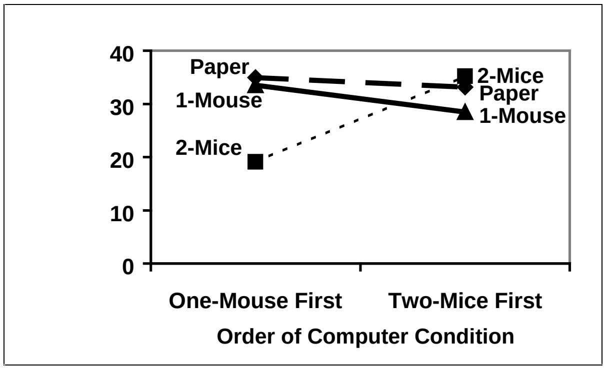

Figure 6. Mean time (seconds) to complete puzzles in the three experimental conditions, categorized by which computer condition the users played first.

6 Discussion

The results presented in this paper clearly demonstrate that users interact concurrently when the medium they are working with supports it. This is a significant finding given that typical desktop computers do not support simultaneous input from multiple users. Concurrent interaction frequently occurs in the real world but is constrained (by technology) when collaborating in a face-to-face computer environment.

An interesting result from this study is the interplay of dependent measures with the computer condition the children played first. It suggests that children's behaviour and performance are impacted by whether or not they first play on a traditional, one-mouse computer, or they instead play first on a computer equipped with two mice. In general, children who played using the one-mouse computer first increased their level of activity in the game, and were able to solve puzzles significantly faster, when they then moved to a computer with two mice. In contrast, children first exposed to the computer with two mice showed no difference in their level of activity or time to solve puzzles when they played in the subsequent one-mouse condition. The children's verbal interactions also exhibited a similar trend, although it was not statistically significant. Improvement over the three sessions, may be natural, given that the children have become more familiar with the game, the puzzles, the experimental setup, and with each other. However, it is also possible that performance may decrease in the third session if the children get bored of the activity.

We hypothesize that these interaction effects may be related to the fact that after playing in a constrained environment (one-mouse), the children flourish when provided with an environment that better supported their desired concurrent interactions. In contrast, when children are switched from the two-mice environment to the traditional computer, they may be frustrated with their inability to interact as naturally as they had in the previous sessions.

An interesting informal observation from this study was the difference observed in the children's physical activity between the non-computer and computer-based conditions. When children played in the paper condition, they were physically and mentally engaged in the activity. Figure 7(a) shows two boys with their arms intertwined, placing pieces all over the board, both working towards a solution. In every paper-based session, both children chose to physically hold and place pieces, and the physical sharing of the pieces occurred naturally. In contrast, children were less physically engaged, when interacting with a mouse, in the computer-based conditions (b & c). They often sat still, directing their view primarily towards the computer screen. Passing objects between the participants was also less intuitive. This lack of physical engagement may impact the overall effectiveness of the collaboration, through decreased user performance, motivation, and naturalness of interactions (both human-computer and human-human interaction).

(a) (b) (c)

Figure 7. Children playing in each condition: (a) paper condition, (b) one-mouse condition, and (c) two-mice condition.

7 Conclusion and Future Work

The results presented in this paper, along with the preliminary results of this work, provide a strong justification for research in the area of Single Display Groupware (SDG). Existing computer technology does not effectively support the richness and complexity of users' face-to-face interactions and often, natural interactions are stifled as users conform to the constraints of traditional computing environments. This work is a first step in understanding how the introduction of alternative technologies affects users' collaborative interactions. An important next step includes performing similar studies in different environments. Distinct user groups have different interaction dynamics and therefore it is important to examine each individually.

This research examined the results of allowing different types of interaction, however, the precise reasons *why* behaviours differed under these conditions are still unknown. We plan to explore fundamental reasons why user behaviour changes when different interaction possibilities are provided. Isolating the factors that affect behaviour will make it possible to form a set of guidelines for the development of groupware applications. Moreover, it is desirable to extend this research to include interaction techniques that do not have physical world counterparts, but also do not conflict with users' natural interactions. Augmented workspaces are an example where, often, the interaction styles do not have a physical world counterpart, but could potentially be included in a work environment without compromising natural interactions.

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