Understanding Children's Interactions in Synchronous Shared Environments

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ABSTRACT

Traditional computer technology offers limited support for face-to-face, synchronous collaboration. As a result, children who wish to collaborate using computers must adapt their interactions to the single-user paradigm most personal computers are based on. More recently, co-located groupware systems offering support for concurrent, multi-user interactions around a shared display have become technologically feasible. Unlike traditional groupware systems that provide multi-user interaction through the use of separate computers, these systems share the physical workspace, as well as the virtual workspace. These systems provide a unique mechanism through which children can interact with each other. However, ways to best utilize the technology in this manner has not been fully evaluated. This paper investigates how technological support for children's synchronous interactions facilitates their collaborative activities. In particular, we examined whether a shared workspace facilitates the development of a shared understanding during a computer-based collaborative activity. We present a field study that observed pairs of children playing an educational game in several display configurations. The findings from this research suggest strengths and weaknesses of various types of support for synchronous interactions and discusses issues related to the design and development of more effective computer systems to support children's face-to-face interactions.

KEYWORDS

Shared environments, co-located collaboration, Computer Supported Cooperative Work (CSCW), Computer Supported Collaborative Learning (CSCL), educational games, children, experimental evaluation, communication

INTRODUCTION

Despite the many technological advances to support distributed interactions, people still spend a great deal of time traveling by air/car/train to meet face-to-face with colleagues, family, and friends. There is something very engaging about interacting in a face-to-face environment. Numerous research and commercial endeavors have investigated technological advances in an attempt to capture the essence of face-to-face interactions and to effectively support people working at a distance [5, 6, 13, and 23]. Most groupware research assumes that face-to-face collaboration provides a richer experience [6], and thus distributed groupware systems are often designed to recreate the feeling of "being there" [7, 13]. However, an equally important endeavor is the exploration of how technology can enhance and improve users' co-located interactions. This is especially important when considering children's use of technology. Emergent environments such as home-use and portable computing are causing researchers to question the fundamental designs that society has adopted as representative of a computer. Traditional interaction paradigms, such as the one-keyboard one-mouse paradigm can be constraining to users and are slowly giving way to more flexible technologies, such as large screen displays [20, 27, 29] and handheld computers [19]. Still, these new technologies are not sufficiently addressing the needs of all users, specifically multiple children sharing machines in the classroom [12].

Distance learning is currently a major research and industrial focus worldwide while the re-design of hardware and software to support co-located learners in a classroom environment is explored less frequently. Also, the use of smaller and less expensive handheld computers in the classroom has been investigated for unique interaction patterns in collaborative educational applications [16]. However, in most classrooms today, synchronous collaboration is supported in three different ways: 1) by having children work together at the same computer; 2) by having children work together on side-by-side computers; and 3) by having children work with others at a distance through networked computers. By understanding students' communication and interaction patterns in these three configurations, we can gain new insights into the strengths and weaknesses of each approach and discover issues related to the design and development of more effective interactive systems for face-to-face collaboration.

This work investigates children's interactions while playing a puzzle-solving mathematics game in various collaborative configurations. In particular, we examine issues surrounding a shared understanding in a collaborative task. Much of the previous literature on cooperative learning suggests that shared goals, tasks, resources and roles enhance shared understanding and allow for an effective cooperative learning experience [see 9 for an overview].

This paper presents research related to co-located collaboration. This is followed by a description of our field study, the methodology used, and the data collection and analyses. Empirical results are presented and analyzed in terms of the variation between experimental conditions and the collaborative process within experimental conditions. Finally, we discuss the impact of this work for supporting co-located collaboration, along with directions for future work in the area.

Background

The rich information available in co-located collaborative environments has spurred researchers to find novel ways of supporting multiple people working together around a shared display. Research in Single Display Groupware (SDG) systems [26] have explored the development of co-located multi-user environments including connecting individual computers to one large, passive display [30], creating large, shared interactive displays [20], and providing multiple peripherals on a shared computer [26]. Research on large interactive display systems has been driven primarily by desire for meeting-room support [20, 27]. Several types of interactive displays have been developed including electronic whiteboards [20], interactive wall displays [28], and tabletop displays [28]. These systems currently offer only limited support for concurrent multi-user interactions and they require specialized, expensive hardware, making them unavailable to the average user. Early work on augmenting individual displays with shared, large screen display systems included the Colab [30] and the CourtYard [29] systems. Both systems networked several desktop computers together and connected these to a large-screen display in the same room. More recently, Myers et al. [19], have extended this idea by connecting handheld computers to a shared display, creating a more flexible, portable, and scalable hardware setup.

These aforementioned studies have been primarily focused on supporting co-located collaboration in the workplace. While this is important groundwork, the domain of children working together in the classroom has unique issues and considerations. Children are smaller than adults, have no access to resources beyond what is provided at school or through their parents, and have different goals. While professionals and students both have the motivation of deadlines imposed by organizations or teachers, children need to experience enjoyment from their computer interactions in order to continue investigating the possibilities that technology has to offer [11]. There are many exciting toys and leisure activities competing for children's time and interest. Children enjoy playing together and studies have shown that social interactions in a learning environment lead to significant learning benefits [9, 14] and that there are positive academic and social benefits to having children work together in groups [9, 14].

In order to support children working together while maintaining the existing technological infrastructure available in most schools, current systems have been extended to accommodate multiple children using one computer. This has been accomplished using peripheral devices, such as styli [1], joysticks [3], and mice [25, 26], to provide multi-user interaction. While these support for face-to-face collaboration can make the technology more accessible when collaborating, these solutions still require specialized software development since most software has been designed and implemented for use by a single user.

Previous research suggests that shared displays provide certain advantages when computers are being used for collaboration [10]. Sharing a display provides a shared artifact for collaborators to use in their conversation, which has been shown to increase attention and involvement during a collaborative task [2]. Furthermore, research suggests that users subconsciously respond to computers as social actors, potentially complicating the task of discussing shared objects located on different screens [21].

Although providing a shared display for co-located collaboration seems intuitive (i.e. it is a natural way to interact), research has not clearly demonstrated that a shared display system supports concurrent multi-user interaction as well as alternative display configurations such as side-by-side monitors, or distributed, networked computers. Children are very good at engaging in rich face-to-face social interactions. Research has shown that students can become more motivated and successful when these interactions are supported [12]. Our study employed both quantitative and rich qualitative measures to elucidate why these designs are successful and to evaluate the effectiveness of several display configurations on a collaborative task.

FIELD STUDY

To better understand children's interactions in synchronous shared environment, we observed children playing a collaborative mathematical computer game. The children were given the opportunity to play the game in various configurations to support their collaborative interactions.

Students and Setting

Twenty-four grade seven students aged 11 to 13 (14 girls and 10 boys) from Lord Nelson Elementary School volunteered to participate in the study. Lord Nelson is located in a lower socioeconomic, culturally diverse area of Vancouver, British Columbia, Canada. Consent to participate was obtained from all children and their parents. The children played the game in the a small room off the school's library and the researchers remained in the room to monitor the equipment, address issues with the software, and take field notes of the children's interactions.

The children played the game using an IBM-compatible PC with two universal serial bus mice. They used either one or two 19-inch monitors, depending on which collaborative setup they were playing in. When each student was given their own monitor, a VGA splitter was used to send the same output to the two monitors to simulate networked computers. This ensured that the hardware performance was consistent across all three playing conditions. Observations of the children's play were recorded by two video cameras, each with a lavaliere microphone. The children also wore audio headphones through which they could hear the output from their partner's microphone. While this was necessary in the distributed condition, it was also provided in the other configurations to minimize the novelty effect if the audio equipment. Although this decision was important for the quantitative analyses, it may have negatively impact the qualitative data gathered from the non-distributed configurations.

Play Conditions

The children played the game in three different collaborative configurations: a shared configuration, a side-by-side configuration, and a separated configuration. In the shared configuration the subjects were seated beside each other, sharing a monitor (see Figure 1a). In the side-by-side configuration the subjects were seated beside each other, each having their own monitor (see Figure 1b). In the separated configuration, subjects were seated in the same room, each with their own monitor attached to the same computer, but visually separated by a divider (see Figure 1c). In each collaborative configuration, the children had their own mouse to control their own on-screen character.

(a) **(b)** **(c)**

Figure 1: Kids played the game in three different display configurations. a) Shared display configuration, b) Side-by-side display configuration, c) separated display configuration.

Game Description

The game the children played was a mathematical game called Prime Climb (see 15), originally developed as a part of a distributed multi-player game, Avalanche. Avalanche was developed by the Electronic Games for Education in Math and Science (E-GEMS) group at the University of British Columbia [15]. The Prime Climb game was modified by our research group to produce a stand-alone version that supported multi-user interactions on a single computer. The MID Java API, developed by Hourcade and Bederson [8], was used to support concurrent, multi-user interactions within the game.

The goal of Prime Climb is to guide a pair of climbers to the top of a mountain, and to complete as many mountains (levels) as possible. To finish a level, players must work together to move their on-screen characters to the top of a mountain consisting of stacked hexagon blocks. Players move to new positions by mouse-clicking on hexagons that have numbers displayed inside them. Two climbers are displayed on the screen (red and blue), each controlled by a cursor of the corresponding colour. The climbers are connected by a rope that can span at most three hexagons. Climbers can move only to a space adjacent to their current location and must avoid obstacles (mountain goats, rocks, and trees).

The main rule of the game is that the two climbers can never be positioned on numbers that have a common factor other than one. If a player chooses an illegal number, their climber falls off of the mountain and begins swinging by the rope two levels below his/her partner. A swinging player must select a nearby number on the mountain to stop swinging. If a swinging player chooses an illegal number again, his/her partner falls and begins swinging. An additional feature of the game is an ice pick, located in the upper-left corner of the game window. Dragging the ice pick to the mountain and dropping it onto a hexagon decreases the value in the hexagon by one, to a minimum of one. When the players reach the top of a mountain, a new mountain appears for the next level of the game. Levels increase in difficulty by adding more obstacles, using larger numbers, and increasing the height of the mountains.

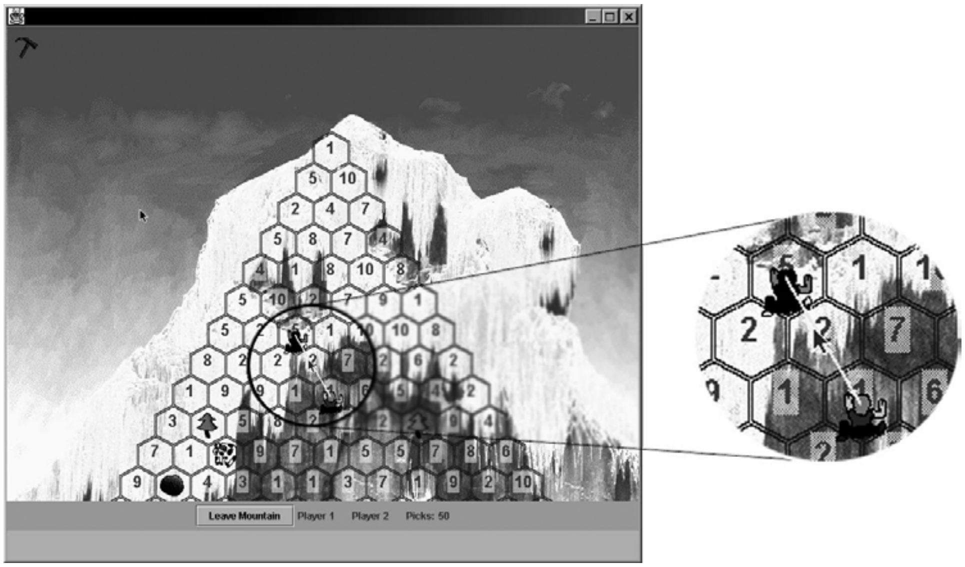

Figure 2: Screen shot of the Prime Climb game.

Game Playing Sessions

Each pair of students was excused from class on three separate occasions, and were given the opportunity to play the game in each of the collaborative configurations. During the first session, the students completed a background questionnaire to gather information on their exposure to computers and games. Following this, the rules of the game were explained and the children were given 15-minutes to play the game in one of the collaborative configurations. The children then returned for two additional 15-minute sessions to play in the remaining two collaborative configurations. After each session, the children filled out an interface evaluation questionnaire to elicit opinions on game difficulty, enjoyment level, and mutual understanding during their play. When a pair of students had completed all conditions, they filled out a post-experiment questionnaire to determine overall impressions of the game and feedback on the three collaborative configurations.

The study spanned two weeks, during which pairs did not play in more than one session on the same day. The order in which the children played using the collaborative configurations was counterbalanced to avoid any order effects. Due to illness, two pairs were unable to complete the experiment and data for only 20 children were fully collected[1].

Data Analyses

Both quantitative and qualitative data were gathered from several sources during the study, including field notes, video, questionnaires, and computer logging. Computer log files tracked performance data including the number of mountains completed, the game events, and the number of errors. Verbal and non-verbal communications were analyzed from the video data using the MacShapa™ video analysis system [24]. Inter-rater reliability was found to be high for both the verbal and non-verbal coding schemes. A two-pass coding procedure was used to minimize the number of events missed due to pausing and rewinding the video. In the first pass, the events were logged, without assigning start and end points. In the second pass, the start and end points for each recorded event were logged, and any additional events missed in the first pass were recorded. Video data for a subset of the participants were transcribed and annotated with corresponding field notes and computer log data. The conversation and gestures were coded and analyzed iteratively using the NVivo™ qualitative analysis software package [22]. Three pairs, two female pairs and one male pair, were selected based on the order in which they performed the experimental conditions. Finally, questionnaire data from all pairs were analyzed to provide further insights.

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[1] The two pairs were each scheduled to perform separate display configuration orderings; thus, data from at least one pair playing in each experimental ordering was collected.

The decision to employ qualitative techniques together with quantitative research methods is well supported in the literature. Both methods have their own strengths and logic and are best used to address their corresponding research purposes [17]. Quantitative methods are best used to examine the differences between experimental conditions whereas qualitative methods are best used to examine the process across or within experimental conditions. Both methods are empirical in that they involve rigorous and systematic inquiry that is grounded in the data. Used together, the two methods can be quite complementary [4, 18]. Qualitative data can be used to supplement, validate, explain, illuminate, or re-interpret quantitative data gathered from the same setting [18], overcoming abstraction and using details to build up a gestalt for the reader [4].

DISCUSSION OF RESULTS

The goal of the present study was to gain insight into the strengths and weaknesses of sharing a display, when support for concurrent activity is provided. Data were collected to promote understanding of students' interactions and communication patterns when collaborating in different display conditions. After a brief vignette, we present and discuss some of the insights gained during the study and subsequent analyses of the data. The vignette illustrates the type of interactions that occurred during the game play.

> *Betty and Sarah are trying to finish a difficult level as fast as they can and are finding it difficult to make it up the mountain without falling. Sarah is instructing Betty where she should go by calling out the numbers of where she wants Betty to move. Betty falls when she and Sarah move simultaneously without conferring on where to go. She suggests that they should use a strategy where she stays on odds and Sarah stays on evens. They take turns moving up the mountain and then begin to play in parallel when they are comfortable with their new strategy, sometimes calling out their intent by simply saying a number. Unfortunately, Sarah falls near the top and has nowhere to land without making Betty fall. Betty grabs the 'pick' and decrements a number above where Sarah is swinging so that Sarah could safety land there. Together they finish the level and Sarah does a 'chair dance' of excitement.*

Multi-User Interaction Styles

When children work together, they often use a variety of collaboration styles, such as divide and conquer, or group consensus. The collaboration styles that are available to children working on a typical computer can be restricted by the interaction technology (e.g., only one mouse and one keyboard). In this field study, the technology supported simultaneous multi-user interaction. Providing the children with this additional resource increased the potential flexibility of their collaboration process. However, the constraints of the game were determining factors as well. In particular, two rules of the game that affected the children's collaborative interactions were: 1) the players could move at most three positions away from each other; and 2) the validity of the number chosen by one player was related to the current position of the other player. These rules forced tightly coupled play and made it challenging to interact simultaneously. Nonetheless, informal observations during the children's sessions indicated that some pairs chose to interact concurrently. To help understand the type of interactions used by the children, including when they took advantage of the ability to interact simultaneously, we performed in-depth analyses of the experimental sessions for three of the ten student pairs. These analyses were based on the rough picture of the students' on-screen interactions that was provided by combining the computer logs with the session transcripts for these pairs.

Given the rules of Prime Climb, the simplest interaction style is strict turn-taking. This allows the students to evaluate the partner's current number before choosing a new position. Interestingly, the pairs did not always use this interaction style. Although the players started the experiment using strict turn-taking, some players preferred to make multiple moves per turn, some pairs developed strategies that allowed players to select numbers independently of the partner's current position, and some pairs preferred to move up the mountain quickly, in parallel. The parallel interaction style required each player to anticipate the partner's next move and then to quickly choose a compatible number.

To mitigate the challenges of interacting concurrently within the game, some of the pairs negotiated play strategies. One pair developed a strategy based on the type of numbers each player should land on, creating an "odds or evens" strategy. This strategy worked well until the numbers became large. Another play strategy that was not as successful used several short-term strategies unrelated to the numbers. For instance, players would climb along the edge of the mountain because they felt it would be easier.

The players' goals also influenced their interaction styles. For example, the primary goal of two of the pairs who interacted concurrently seemed to be to finish as many mountains as possible during the session. Conversely, a third pair rarely interacted simultaneously, possibly due to the players' conflicting goals. One girl appeared intent on reaching the top of the mountains quickly, but her partner seemed more intent on having fun by antagonizing her.

Overall, the goals of the players affected whether or not a pair developed a game strategy and the game strategy affected the interaction style used by the players. Consequently, the children interacted in a variety of ways with the same hardware technology and software application. Although the in-depth qualitative analyses were only performed on three pairs, the findings support informal observations made of the other 17 pairs during the experiment. This indicates that technology, especially multi-user technology, needs to be flexible to account for this variation in interaction styles.

Communication

Our presupposition with regard to display conditions was that a shared display would lead to a shared understanding of the workspace. When people view shared objects in the physical world, an individual has an understanding of both where the object is and where their partner is in relation to themselves. This helps provide an implicit understanding of how their partner views the object, potentially leading to a better shared understanding of the workspace. If artifacts in a virtual scene are analogous to objects in the physical world, this same result may hold for virtual objects on a shared display. However, it is unclear whether or not this phenomenon extends into shared virtual workspaces when users have separate visual displays or are in separate physical locations.

Both qualitative and quantitative analyses suggest that reaching a shared understanding of the workspace was more difficult when the children were discussing on-screen objects in the conditions where they had separate visual displays. Consider Excerpt 1, which was taken from one pair of children playing in the side-by-side display condition. In this excerpt one player, Scott, has just tried to move to a number that shares a factor with his partner's current position. This action causes Scott's climber to fall off the mountain and start swinging below David's player. David suggests that Scott move to "the 7" and he points at that position on his own screen. Scott does not see where David is pointing though because Scott is still looking at his own display. While clarifying his suggestion, David looks at the mountain on Scott's screen, even though their two displays are showing the identical scene.

Excerpt 1. Two children playing the game in the side-by-side display condition.

[Scott's climber falls. David and Scott are both looking at their own displays.]

David: *Oh...come up!* [David points to his own display to show Scott where he should "come up". Scott is still looking at his own display]*... oh* [David seems to realize that Scott did not see where he was pointing]

[David leans back from his own monitor and turns to look at Scott's screen]

David: *Go to the 7...the bottom one.* [Scott continues to try to get his climber back on the mountain]

Scott: *This one?* [Scott is still looking at his own screen]

David: *Yeah.* [Scott's climber is back on the mountain. David turns back to his own screen and resumes playing]

This excerpt suggests that reaching a shared understanding regarding on-screen objects is facilitated by sharing a physical display.

Data gathered from the questionnaires also supports the notion that a shared display can facilitate collaboration. After completing each display condition, the students were asked to rate how well they understood their partner, on a five-point scale (one corresponded to 'always' while five corresponded to 'never'). A Friedman two-way analysis of variance revealed a marginally significant difference between the display conditions, $\chi^2(2,N=20)=5.5$, $p=0.063$. On average, students reported more strongly that they understood their partner in the shared condition (M=2.3, SD=1.3) than either in the side-by-side condition (M=2.7, SD=1.3) or in the separated condition (M=2.6, SD=1.4). A similar trend was also apparent in student's responses when asked, in each condition, how well they felt their partner understood them. These differences, although subtle, support the notion that a shared display can help foster a shared understanding. Students felt strongly that there was mutual comprehension in their communication when they viewed the virtual scene on the same physical display. However, in the side-by-side and separated condition, even though the virtual scene was identical when viewed on separate screens, these display configurations did not appear to evoke the same degree of response.

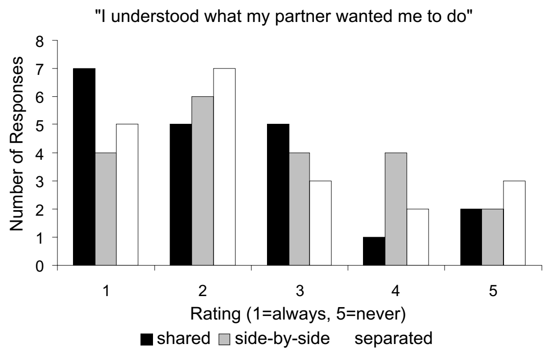

Figure 3: Questionnaire responses to the question "I understood what my partner wanted me to do". The number of responses to each rating on a five-point scale (1=always, 5=never) is shown for each display condition.

Effect of Display Condition on Student's Game Perception

If a shared display leads to a shared understanding of the workspace, it can be argued that it should be easier for students to work together and solve puzzles. After each experimental condition, the students were asked to rate how easy the game was to play on a five-point scale (one corresponded to 'easy' and five corresponded to 'hard'). A Friedman two-way analysis of variance revealed a significant difference for perceived ease of use between the display conditions, $\chi^2(2, N=20)=10.7, p<.01$. The students, on average, rated the shared condition as being easier to play (M=2.3, SD=0.9) than the side-by-side (M=2.8, SD=0.8) or the separate condition (M=2.9, SD=0.8). Since the students only played for a short amount of time (15 minutes), and because the software crashed during some of the sessions, it was not possible to compare the number of mountains (game levels) completed in each condition. As a result, the performance data could not be used to validate the students' perceptions of how easy it was to solve puzzles in each of the conditions.

Table 1: Why children found the game easier to play in the different display configurations.

Why	# of Remarks	Example Remark
Shared display:		
Close to partner	7	"We were right beside each other so we knew what to do"
Ability to point and do things for partner	3	"If your partner didn't understand, you could do it for them"
Better communication	2	"We could see each other and communicate better"
Same display	2	"Because we had the same screen"
No reason given	1	
Side-by-side display:		
Separate displays	2	"You get your own screen"
Ability to point	1	"They could point out what you're doing wrong"
Better understanding	1	"If you win you can see if she's happy or not, then you know what happened"
Separated Displays:		
Order related	1	"We did it last so we were getting used to the game"

Although these results are subjective, and may have been influenced by external factors unrelated to the display configuration (e.g. time of day, mood, partner's behaviour), they are also supported by the post-experiment questionnaire[2]. Fifteen of the twenty children stated that the shared condition was the easiest of the three display conditions to solve puzzles in (χ^2(2, N=20)=16.3, p<.001). Thus, the children's perception that it was easier to play in the shared condition was consistent for both the evaluation of the interface after each condition, and the overall evaluation at the end of the study.

On the post-experimental questionnaire, the children reported why they found it easiest to solve puzzles in the shared condition. The majority of their comments related to the fact that they could communicate more effectively and could help each other when they were "right beside each other", in the shared display configuration. Table 1 groups the children's responses into several categories for each display configuration along with an example remark for each.

Non-verbal Interactions Between Students

The impact of the display configurations on the children's non-verbal interactions with each other is important to understand. In the physical world, our non-verbal interpersonal interactions are very refined and play an important role in our activities. How a computer environment enhances or impedes these interactions will ultimately impact its effectiveness as a collaborative environment.

Pointing

The number of times children pointed in the various display conditions was gathered in the non-verbal coding of the video data. In general, the children rarely pointed in any of the display conditions. Overall, six occurrences of pointing were recorded in the shared condition, compared to only two occurrences in the side-by-side condition, and one in the separated condition. In face-to-face activities, pointing while interacting with shared artifacts is common and often helps to augment the verbal communication. Our results, however, showed that this mode of communication was not utilized when children played in the two face-to-face conditions.

The limited number of pointing gestures throughout the study may be explained by the introduction of a virtual non-verbal communication channel, which becomes available when users are provided their own on-screen representation, e.g. their own cursor. It is possible that children chose to "point" using their cursor as opposed to their hand. Further investigation is required to understand how this extra communication channel augments or replaces physical gestures. No screen feed data was available so we could not explore this issue in the current study.

Looking at Their Partner

In both the shared display and side-by-side conditions, it was possible for the players to see their partners. However, video analyses revealed that players looked at their partner more often in the side-by-side display configuration (105 occurrences) than in the shared configuration (85 occurrences). Although this difference was not statistically significant, the trend suggests that students in the side-by-side condition may have looked at their partner more often to increase awareness of their partner's actions. Visual focus may also have played a role in the users' awareness of each other's actions. In the shared display configuration, the students' attention was focused on the same physical artifact (the computer screen); thus, their partner was relatively close to the player's center of visual focus. Conversely, in the side-by-side condition, both the separate displays and the increased distance between players caused partners to be further away from each other's center of visual focus when looking at their own displays. As a result, a player's awareness of their partner's actions may have decreased in the side-by-side condition causing them to actively look at their partner more often to see their partner's physical actions.

Enjoyment

After playing in each condition, students were asked to rate how much they enjoyed playing the game on a five-point scale (one corresponded to 'fun' while five corresponded to 'not much fun'). No significant differences between the conditions were found, χ^2(2, N=20)=4.1, ns, and in general, the students rated all three conditions as being somewhat fun (shared: M=2.4, SD=1.4; side-by-side: M=2.75, SD=1.52; separated: M=2.6, SD=1.4). After playing in all conditions, students were asked to choose which condition was the most fun to play. Of the twenty students, nine chose the separated condition, six chose the shared condition, and five chose the side-by-side condition. This difference was also not found to be significant, χ^2(2,N=20)=1.3, ns. The children's explanations of their choices were grouped into several categories for each display configuration. These are shown in Table 2, along with an example remark for each category. The high variability of these results, compared with the results of which display condition was easiest to use, indicates that the children do not necessarily

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[2] The post-experiment questionnaire was completed after all three display conditions were played. This allowed the children to express their preferences across the display conditions, e.g., in which condition the game was easiest to solve puzzles. This questionnaire was in addition to the one the children completed after each condition to evaluate the specific display condition in which they had just played.

equate the easiest collaborative environment to the most fun environment. In fact, four students commented that they enjoyed the challenge of the separated display configuration.

Table 2: Why children found the game more fun to play in the different display configurations.

Why	# of Remarks	Example Remark
Shared display:		
Sharing a display made it easier	3	"It was easier with one monitor which made it more fun"
Can point at the display	1	"She can point out which ones for me to go to"
Miscellaneous	2	"It was the first time I played the game"
Side-by-side display:		
Beside each other, but had own display	2	"You have your own monitor but you can see your partner"
Can see partner	3	"You can see the expression on their face when you mess up"
Separated Displays:		
Needing the microphones	2	"You actually needed the mikes and it was cool"
Being separate was more challenging	4	"We couldn't see each other so it was more challenging"
Couldn't see partner's actions	2	"You couldn't see what the other was doing"
Miscellaneous	1	"It was similar to an Internet game and talking to a friend combined"

A second factor that contributed to children preferring the separate display configuration was the necessity of the audio equipment (headphones and microphones) for communication in that condition. The ability to use technology to communicate with a partner, when they were separated, was very engaging for the children. As a result, several children mentioned this novelty factor as their reason for preferring the separated condition. In contrast, the use of audio equipment in the other two configurations was not essential for communication given that they were face-to-face. Consequently, even though audio equipment was utilized in these two conditions, it appeared to be less of a contributing factor to children's engagement.

Playing with a partner also added to the children's enjoyment of the game. Analysis of the post-experimental questionnaires revealed that many of the students felt that having a partner made it easier to finish mountains (levels) in the game. This preference was expressed by fifteen students when they played the shared condition, fifteen students when they played the side-by-side condition, but only eleven students when they played the separated condition. This difference was found to be marginally significant, $\chi^2(2, N=20)=5.3$, $p=0.069$. In addition, fifteen of the twenty children reported that they enjoyed playing with a partner. Providing children with technology that supports multiple users allows children the option of playing and/or working on computers with friends.

CONCLUSIONS AND FUTURE WORK

The results of this work further our understanding of how children interact in synchronous shared environments. In particular, the physical proximity of participants, the ability to utilize gestures, and the use of a shared physical workspace, all positively influenced the students' collaborative experiences. In the physical world, these interactions are a natural part of our daily lives. Unfortunately, current technologies do not adequately support these interactions in a seamless manner. Continued work in this area is needed to fully understand its full potential for collaborative learning environments.

Although we observed many interesting trends, these results must be interpreted with caution. The small sample size, limited playtime, and high variability among the pairs limited these analyses. Although there were hints of behavioural change, fifteen minutes of play may not have been long enough for the children to develop an interaction style suited to a particular display configuration. Future longitudinal studies where subjects are given time to adapt to each display condition will help address such issues.

Other areas for future investigation include the type of collaborative task and the application domain. The present study required users to work together to reach the top of the mountain by solving mathematical problems. With such tightly coupled group work, partners may not have had the opportunity to explore alternative collaborative interaction styles afforded by each of the display configurations.

Most importantly, beyond all of the intricate analyses, we ultimately cannot forget the preferences of those who will inevitably interact with these systems. Some students vocalized that they preferred the shared display simply because they "had the same screen", but could not articulate why this configuration was important to them. More astute students were able to describe the essence of the shared display configuration. One female student felt that the physical proximity and shared screen enhanced communication, while a twelve-year-old boy commented that the shared display was easier to use because "cooperation [was] dynamically increased". Although this is a complex research endeavor, the children effectively captured the spirit and fundamental quality of the experience – having fun.

REFERENCES

1. Bier, E.A., & Freeman, S. (1991). MMM: A User Interface Architecture for Shared Editors on a Single Screen. In *Proceedings of UIST '91*. 79-86.
2. Bly, S. (1988). A Use of Drawing Surfaces in Different Collaborative Settings. In *Proceedings of CSCW '88*, 250-256.
3. Bricker, L.J., Bennett, M.J., Fujioke, E., & Tanimoto, S.L. (1999). Colt: A System for Developing Software that Supports Synchronous Collaborative Activities. In *Proceedings of the Ed-Media Conference*, 587-592.
4. Firestone W. (1987). Meaning in method: The rhetoric of quantitative and qualitative research. *Educational Researcher (16),* 16-21.
5. Fish, R.S., Kraut, R.E., & Root, R.W. (1992). Evaluation Video as a Technology for Informal Communication. In *Proceedings of CHI '92*, 37-48.
6. Gutwin, C., Greenberg, S. & Roseman, M. (1996). Workspace Awareness in Real-Time Distributed Groupware: Framework, Widgets, and Evaluation. In *People and Computers XI (Proceedings of HCI '96)*, 281-298.
7. Hollan, J. & Stornetta, S. (1992). Beyond Being There. In *Proceedings of CHI '92*, 119-125.
8. Hourcade, J. & Bederson, B. (1999). Architecture and Implementation of a Java Package for Multiple Input Devices (MID). Technical Report CS-TR-4018 University of Maryland.
9. Hymel S., Zinck B., & Ditner E. (1993). Cooperation versus competition in the classroom. *Exceptionality Education Canada*, 3:1-2, 103-128.
10. Inkpen, K., Booth, K.S., Klawe, M., & Upitis, R. (1995). Playing together beats playing apart, especially for girls. In *Proceedings of CSCL '95*, 177-181.
11. Inkpen, K. (1997). Three Important Research Agendas for Educational Multimedia: Learning, Children and Gender. *Proceedings of Educational Multimedia '07, Calgary AB, June 1997,* 521-526.
12. Inkpen, K.M., Ho-Ching, W., Kuederle, O., Scott, S.D., & Shoemaker, G.B.D. (1999). "This is fun! We're all best friends and we're all playing.": Supporting children's synchronous collaboration. In *Proceedings of CSCL '99*, 252-259.
13. Inoue, T., Okada, K., & Matsushita, Y. (1997). Integration of Face-to-face and Video-mediated Meetings. In *Proceedings of GROUP '97*, 405-414.
14. Johnson D.W., Maruyana G., Johnson R,T, (1981). Effects of cooperative, competitive, and individualistic goal structures on achievement: A meta-analysis. *Psychology Bulletin, 89(1),* 47-62.
15. Klawe, M. (1998). When does the use of computer games and other interactive multimedia software help students learn mathematics? In *Proceedings of the Technology and NCTM Standards 2000 Conference*.
16. Mandryk, R.L., Inkpen, K.M., Bilezikjian, M., Klemmer, S.R., & Landay, J.A. (2001). Supporting Children's Collaboration Across Handheld Computers. In *Extended Abstracts of CHI, Conference on Human Factors in Computing Systems.* Seattle, USA, April 2001.
17. Maxwell J.A. (1996). *Qualitative Research Design: An interactive approach.* Thousand Oaks: Sage.
18. Miles M.B. & Huberman A.M. (1994). *Qualitative Data Analysis (2^{nd} Ed.).* Thousand Oaks: Sage.
19. Myers, B.A., Stiel, H., & Gargiulo, R. (1998). Collaboration using multiple PDAs connected to a PC. In *Proceedings of CSCW '98*. 285-294.
20. Pederen, E. McCall, K., Moran, T., & Halasz, F. (1993). Tivoli: An Electronic Whiteboard for Informal Workgroup Meetings. In *Proceedings of InterCHI '93*. 391-398.
21. Reeves, B., & Nass, C. (1996). *The Media Equation*, Cambridge University Press.
22. Richards, L. (1999). *Using NVivo in Qualitative Research*, SAGE Publications, London.

23. Roseman, M. & Greenberg, S. (1992). GROUPKIT: A Groupware ToolKit for Building Real-Time Conferencing Applications. In *Proceedings of CSCW '92*, 43-50.

24. Sanderson, P.M., McNeese, M., & Zaff, B. (1994). Knowledge elicitation and observation in engineering psychology: MacSHAPA and COGENT. *Behavior Research Methods, Instruments, and Computers*, 26, 117-124.

25. Scott, S.D., Shoemaker, G.B.D., & Inkpen, K.M. (2000). Towards Seamless Support of Natural Collaborative Interactions. In *Proceedings of Graphics Interface 2000*, 103-110.

26. Stewart, J., Bederson, B.B, & Druin, A. (1999). Single Display Groupware: A Model for Co-present Collaboration. In *Proceedings of CHI '99*, 286-293.

27. Streitz, N.A., Geibler, J., Haake, J.M., & Hol, J. (1994). DOLPHIN: Integrated Meeting Support across Local and Remote Desktop Environments and Liveboards. In *Proceedings of CSCW '94*. 345-358.

28. Streitz, N.A., Geibler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., & Steinmetz, R. (1999). i-LAND: An Interactive Landscape for Creativity and Innovation. In *Proceedings of CHI '99*, 120-127.

29. Tani, H., Horita, M., Yamaashi, K., Tanikoshi, K., & Futakawa, M. (1994). Courtyard: Integrating Shared Overview on a Large Screen and Per-user Detail on Individual Screens. In *Proceedings of CHI '94*. 44-50.

30. Tatar, D.G., Foster, G., & Bobrow, D.G. (1991). Design for Conversation: Lessons from Cognoter. *Intl. Journal of Man-Machine Studies*, 34, 185-209.