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Understanding children's collaborative interactions in shared environments

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Abstract Traditional computer technology offers limited support for face-to-face, synchronous collaboration. Consequently, children who wish to collaborate while using computers must adapt their interactions to the single-user paradigm of most personal computers. Recent technological advances have enabled the development of co-located groupware systems offering support for concurrent, multi–user interactions around a shared display. These systems provide a unique collaboration environment in which users share both the physical and the virtual workspace. This paper examines how such technology impacts children's collaboration. Findings from this research show that when concurrent, multi–user interaction is supported on a shared display, children exhibit collaborative behaviour similar to their interactions during paper-based activities. The findings also suggest strengths and weaknesses of various mechanisms for supporting synchronous interactions that have implications for the design of computer systems to support children's face-to-face collaboration.

Keywords: Collaboration; Face-to-face; Groupware; Interface; IT-use; Primary; Qualitative; Quantitative; Satisfaction; Secondary; Synchronous

Introduction

Face-to-face collaboration with classmates or friends is an important part of children's daily lives. When they engage in joint activities such as co-authoring an essay, or playing games with others, they often require or desire the use of computer technology. However, in our homes and schools, the predominant one-person/one-computer paradigm limits support for children's face-to-face activities.

Traditional computers are slowly giving way to more flexible technologies, such as large screen displays and handheld computers. Still, these new technologies are not sufficiently addressing the needs of children in today's classroom, where children typically work together either with non-technical media, at the same computer, on side-by-side computers, or at a distance through networked computers. By understanding students' interpersonal interactions in these configurations, insights into the strengths and weaknesses of each environment are gained and issues related to the design and development of more effective interactive systems for face-to-face collaboration are discovered.

This paper presents findings from an on-going research programme aimed at

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supporting collaborative activities in face-to-face environments, such as a classroom. Two studies focused on understanding children's interactions when engaged in synchronous collaborative activities in a variety of collaborative settings. One study, examined how access to multiple input devices on a single computer affected children's interaction with the computer and with each other. The second study, examined how access to multiple displays affected the children's collaboration. The results of these studies are then synthesised into implications for the design of children's collaborative technology. In general, these implications stress the importance of designing flexible hardware and software.

Study 1: Investigating collaborative settings with a shared physical display

Method

This study involved same-gender pairs of children solving puzzles. As shown in Fig. 1, three collaborative settings were investigated: (a) a paper-based version of the game with physical pieces (paper-based); (b) a computer-based version of the game where children shared one mouse and one cursor and (c) a computer-based version of the game where children each had their own mouse and cursor. Children always shared a display in the computer-based settings. The study took place in an elementary school where 40 children (22 girls and 18 boys) between the ages of nine and 11 participated in a puzzle completion game. Based on a number of pre-positioned puzzle pieces and remaining 'free' puzzle pieces, participants determined the pattern, then positioned the free pieces as fast as possible (see Fig. 2).

(a) (b) (c)

Fig. 1. Children playing in each collaborative setting: (a) paper-based, (b) one-mouse and (c) two-mice.

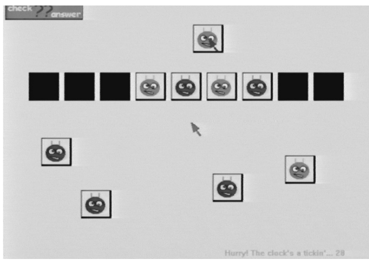

Fig. 2. Sample screen from the game.

Before the experiment, children completed a background questionnaire to indicate their previous exposure to computers and video games. The paper-based version of the game was used as a training session to help the children become comfortable with the game. All pairs played the game in the paper-based setting first with the order of the remaining two collaborative settings counterbalanced. The children played for 10 minutes in each collaborative setting. Finally, the children completed post-experiment questionnaires to determine their overall impressions of the game and feedback on the collaborative settings. Further details can be found in (Inkpen *et al*., 1999; Scott *et al*., 2000).

Results

Quantitative and qualitative analyses of computer log files, videotapes, and questionnaires revealed that providing children with technology that supports concurrent, multi–user interaction can positively impact their engagement, participation, and enjoyment of the activity. Furthermore, when the medium supported concurrent interaction the children took advantage of this capability. The data for the paper-based setting was not considered in the quantitative analysis since all pairs began the experiment with this as a training setting. However, this setting did provide valuable information on how children interacted given a medium that affords unconstrained simultaneous interaction, against which the interactions in the computer-based settings could be compared.

Children's engagement in the activity was determined by the amount of off-task behaviour they exhibited, gathered from the videotapes. Off-task behaviour was considered to be nongame-related actions (e.g. looking around the room) and nongame-related discourse. Video analyses revealed that boredom, frustration with difficult puzzles, and distraction appeared to be the main reasons for off-task behaviour. The results of a mixed ANOVA showed that the children exhibited significantly more off-task behaviour during the one-mouse setting (m = 43.8 secs., $s.d.$ = 70.0 secs.) than in the two-mice setting (m = 13.1 secs., $s.d.$ = 32.1 secs.), $F_{1,32} = 9.835$, $p < 0.01$. No significant differences were found for gender, or order of collaborative setting.

Children also appeared to participate more actively when provided support for concurrent, multi–user interaction. In the two-mice setting, each child was constantly using their own mouse to make on-screen gestures and to move puzzle pieces. The children's participation, though, was not limited to interacting with the game via an input device. In the one-mouse setting, children made verbal comments and physical gestures to provide input when they were not in control of the mouse. A repeated-measures ANOVA showed that, on average, children physically pointed to the puzzle significantly more times in the one-mouse setting (m = 15.5 incidents, $s.d.$ = 7.4 incidents) than in the two-mice setting (m = 2.6 incidents, $s.d.$ = 3.97 incidents), $F_{1,19} = 50.30$, $p < 0.001$. Unfortunately data to examine the extent of on-screen cursor pointing was unavailable.

Tang (1991) has reported that concurrent interaction often occurs when people work together in paper-based settings. Field notes made during the study reported similar concurrent interaction in both the paper-based and two-mice settings. To explore this issue further, data[*] was gathered from the computer logs and the videotapes 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 as the amount of time when neither partner was active.

Not surprisingly, in both the paper-based and two-mice settings, users were frequently active at the same time (37.5% and 27.0% of the time, respectively). In the two-mice setting, the technology enabled both children to interact with the game simultaneously, as did the unrestrictive media available in the paper-based setting. In contrast, in the one-mouse setting the technology forced children to interact sequentially. This clearly demonstrates that users interact concurrently when the collaborative medium supports it, a capability not offered by typical desktop

[*] Data was only available for 14 of the 20 pairs, due to problems with video quality.

computers. Interestingly, children resisted surrendering the mouse to their partners in the one-mouse setting, even during idle periods. A repeated-measures ANOVA showed a significant difference between the average inactivity across collaborative settings, $F_{2,26} = 123.51$, $p < 0.001$. A Tukey's HSD posthoc test showed that there was significantly more time in the one-mouse setting ($m = 374.6$ secs., $s.d. = 22.0$ secs.) when both partners were inactive than in either the paper-based setting ($m = 195.4$ secs., $s.d. = 57.3$ secs.), $p < 0.05$, or the two-mice setting ($m = 173.4$ secs., $s.d. = 27.4$ secs.), $p < 0.05$.

An important informal observation was the dichotomy of the physical behaviour in the paper-based and computer-based settings. When children played in the paper condition, they were extremely engaged in the activity as well as with each other.

Figure 1a (above) shows two boys with their arms intertwined, placing pieces all over the board, both working towards a solution. In the paper-based sessions, all children physically manipulated pieces, and the sharing of the pieces occurred naturally. In contrast, children were less physically engaged (e.g. Figs. 1b, 1c) in the computer-based sessions. Children often sat still, directing their view primarily towards the computer screen. This lack of physical engagement may impact the overall effectiveness of the collaboration, through decreased user performance, motivation, and naturalness of interactions.

Analysis of post-session questionnaires revealed that children significantly preferred playing the game on the computer equipped with two mice (70%) over the other two settings (one-mouse: 17.5%; paper-based: 12.5%), $c^2(2, n = 40) = 24.35$, $p < 0.001$. Nineteen of the 28 children who preferred playing in the two-mice setting explicitly attributed this preference to the fact that two mice were available. Furthermore, the preference for using computers with friends as opposed to alone significantly increased from the background questionnaire (67.5%) to the post-session questionnaire (82.5%), $Z = -2.683$, $p < 0.01$ (Wilcoxon Signed Ranks Test). This increase suggests that children enjoyed the experience of working with technology that supports collaborative activity.

Inspiration for the second study

Children are very good at engaging in rich face-to–face social interactions and this first study suggests that they enjoy working together when using technology that supports these interactions. The success of the two-mice setting inspired us to examine what aspects of that configuration were responsible for creating such positive outcomes. In that setting, children shared a physical computer display and had the capability of concurrent, multi–user interaction through two mice and two cursors. It seems intuitive to think that the same positive outcomes might occur if children were also given individual displays. However, it was felt that sharing a physical display might actually improve collaboration due to a heightened awareness of the other player's actions and intentions. To investigate this issue, it was decided to examine the differences between sharing a physical display (e.g. a shared monitor) and sharing a virtual display (e.g. a shared window over networked computers). In this study, children were seen performing a collaborative computer activity in variety of display configurations. All settings supported concurrent, multi–user interaction with multiple mice input. A summary of the study follows; further details are available in (Scott *et al*. 2002).

Study 2: Investigating collaborative settings with a shared virtual display

Method

This study involved same-gender pairs of children playing a collaborative game. As shown in Fig. 3, three collaborative settings were investigated: (a) a shared display; (b) side-by-side displays and (c) separated displays. In settings (b) and (c), a VGA splitter was used to send the same output to two monitors to simulate networked computers, ensuring consistent hardware performance. In the separated-displays setting, a partition was placed between the students so that they could not see each other. The study took place in a public elementary school with 24 children (14 girls and 10 boys) between the ages of 11 and 13 participating in the study[*].

(a) (b) (c)

Fig. 3. Children playing in each collaborative setting: a) shared-display, b) side-by-side-displays, and c) separated-displays.

Pairs of children were asked to play a collaborative mathematics game in which each child controlled an on-screen character (climber) and they had to work together to climb to the top of a mountain. The mountain consisted of stacked hexagon blocks containing numbers (see Fig. 4).

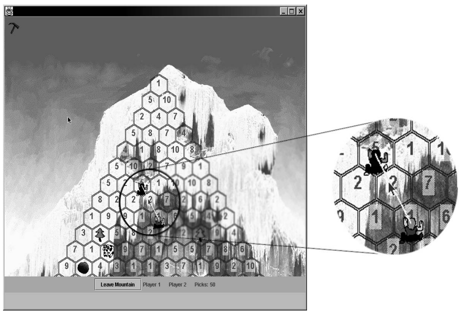

Fig. 4. Sample screen from the collaborative mathematics game.

Climbers could not occupy numbers that share a common factor (other than one) and the distance between climbers could span at most three hexagons (climbers were joined by a rope). Thus, when players moved to hexagons containing common factors, one climber would fall off the mountain to swing below the other climber by their adjoining rope. The goal was to climb as many mountains as possible.

Before the study, students completed a background questionnaire on their exposure to computers and games. The children then played the game for 15 minutes in each collaborative setting, with each session played on consecutive days. The order of presentation of collaborative setting was counterbalanced. After each session, the children completed an interface evaluation questionnaire to collect their opinions on game difficulty, enjoyment, and communication in that particular collaborative setting. Finally, students completed a post-experiment questionnaire to determine their overall impressions of the game and feedback on the three play settings.

[*] Due to illness, two pairs were unable to complete the experiment. However, data from at least one pair playing in each ordering was collected.

Results

To explore the children's collaboration in the different display settings, we examined the children's communication, their collaborative interaction styles, and their feedback on collaborating in the various settings. Quantitative and qualitative analyses of field notes, videotapes, questionnaires, and computer log files revealed that sharing a physical display positively influenced the students' collaboration.

Sharing a display was hypothesized to help children reach a shared understanding of the virtual workspace better than when they had individual displays. A person viewing a shared physical object generally has an understanding of both where the object is and where her partner is in relation to herself, providing an implicit understanding of how her partner views the object. If artifacts in a virtual scene are analogous to physical objects, it seems that this theory may hold for virtual objects on a shared display, fostering a shared understanding of the virtual workspace.

Qualitative analyses of the videotapes showed that the children sometimes had trouble reaching a mutual understanding of the workspace when using individual displays. This is illustrated in the following example of two boys having trouble using side-by-side displays.

> Scott moves his climber onto a number that shares a common factor with David's climber's current position. Consequently, Scott's climber falls off the mountain and starts swinging below David's climber. David says 'Oh . . . come up!' and points (on his own display) to the position of a '7' above Scott's climber. Scott does not see where David is pointing, though, because Scott is looking at his own display. David then turns to look at Scott's monitor and says, 'Go to the 7 . . . the bottom one.' David continues to look at Scott's monitor until Scott's climber lands on the '7', and then David turns back to his own display to continue playing.

The difficulty David had communicating his intentions to Scott demonstrates the difficulty some children had in reaching a shared understanding of the on-screen objects when using individual displays. Video analyses did not reveal such communication problems in the shared-display setting.

If sharing a display fosters the development of a shared understanding of the workspace, it should also make the collaborative task easier to perform. This concept is supported by students' responses on both the interface evaluations (completed after each setting) and the post-experiment questionnaire. On average, students rated the game easier to play in the shared-display setting ($m = 2.3$, $s.d. = 0.8$), compared to the side-by-side ($m = 2.8$, $s.d. = 0.8$) or the separated ($m = 2.9$, $s.d. = 0.8$) displays settings, $c^2(2, n = 20) = 10.7$, $p < 0.01$ (Friedman two-way ANOVA on the interface evaluations). Furthermore, 75% of the children found the game easier to play in the shared-display setting than in the other two settings ($c^2(2, n = 20) = 16.3$, $p < 0.001$, post-experiment questionnaire). In their written comments, children reported that they could communicate more effectively and could help each other because they were 'right beside each other' in the shared-display setting. Whether pairs were actually more successful in the shared-display setting could not be statistically determined in this experiment.

Interestingly, students did not always prefer playing in the shared-display setting. On the interface evaluations, children rated all three settings as being somewhat fun on a five-point scale, where one corresponded to 'fun', and five corresponded to "not much fun" (shared: $m = 2.4$, $s.d. = 1.4$; side-by-side: $m = 2.6$, $s.d. = 1.5$; separated: $m = 2.6$, $s.d. = 1.4$), $c^2(2, n = 20) = 4.1$, *ns*. On the post-experimental questionnaire, when asked to choose which setting was the most fun to play, their preferences varied (shared: 30%, side-by-side: 25%, separated: 45%), $c^2(2, n = 20) = 1.3$, *ns*.

The high variability of these results, compared with the children's perception of which setting made the game easiest, indicates that the children do not equate the easiest collaborative environment to the most fun environment. In fact, four students commented that they enjoyed the challenge of separated displays, while others enjoyed the novelty of separate displays.

In the first study, children tended to interact concurrently whenever the medium allowed it. In this study, the technology always allowed concurrent interaction, but the rules of the game required tightly coupled play. Although strict turn-taking was the simplest interaction style, we observed many pairs interacting concurrently (14.6%, 13.6%, and 21.7% of the time in the shared, side-by-side, and separated display settings, respectively), indicating that multi-user technology should be flexible to allow for these tendencies.

Implications for design of collaborative technology for the classroom

Computers often have to support a variety of classroom activities including working individually, collaboratively, and with others at a distance. The studies summarised above focused on ways of supporting small group activities in several synchronous collaborative settings. The findings have several implications for the design of technology that may be used for collaborative activities as outlined below.

1 *Support should be provided for concurrent interaction.* The results of this work show that this can help to engage children in a collaborative activity and enable them to participate equally. This can also lead to increased enjoyment in the activity, which is important for continued interest (Inkpen *et al*., 1995).

2 *Multiple interaction styles should be supported in both hardware and software.* This will allow children to explore a variety of collaborative strategies and to choose the most suitable one(s) for the activity and their personalities.

3 *Consider designing collaborative applications for use on a shared display*, especially those where the children would benefit from a shared understanding of the workspace (e.g. a spatial learning activity). There are issues beyond the scope of this paper which must be considered when designing collaborative applications for a single display, such as shared navigation and control of shared widgets (Stewart *et al*., 1998; Zanella & Greenberg, 2000).

4 *The goal of the activity should be considered before choosing a collaborative setting.* No collaborative setting is best suited for all situations. As shown above, children who found the collaborative math activity the easiest in the shared-display setting, did not necessarily find it the most enjoyable. Many enjoyed the challenge of communicating in the separated-displays setting. Conversely, if a teacher is trying to coach a child through an activity, sharing a display may help facilitate richer communication to allow them to concentrate on the activity, rather than on trying to understand each other.

Related work

The desire to develop technology that enhances the richness of collaboration in a face-to-face setting has spurred researchers to investigate a variety of multi-user environments, such as large, shared interactive displays (Pedersen *et al*., 1993; Streitz *et al*., 1999), and individual computers connected to one large, passive display (Tatar *et al*., 1991; Tani *et al*., 1994). Most of this technology has been developed to support face-to-face collaboration in the workplace. While this is important groundwork, the success of technology in the classroom has unique issues and considerations. In order to make use of the existing technological infrastructure in schools (mainly personal computers), efforts have been made to extend these current systems to accommodate multiple children using one computer. This has been accomplished by providing multi–user interaction through peripheral devices, such as styli (Bier & Freeman, 1991), joysticks (Bricker *et al*., 1999), and mice (Stewart *et al*., 1998; Stanton *et al*., 2002).

The ultimate goal of technology in the classroom is to foster children's learning. When discovering new technology, children need to experience enjoyment from their computer interactions in order to continue investigating the possibilities of that technology (Inkpen, 1997). This research has shown that children enjoy working on technology that supports cooperative activities. Additionally, collaborative technology can foster social interactions, such as increasing assistance between collaborative partners (Stewart *et al*., 1998), which have been shown to provide positive academic and social benefits (Johnson *et al*., 1981; Hymel *et al*., 1993).

Conclusions

This research explores how various collaborative settings affect children's interactions with each other and with technology. The findings indicate that when technology supports concurrent input to an application, children appreciate and take advantage of this feature. Furthermore, forcing children to share one input device contributes to off-task behaviour and boredom with an application. One solution is to provide concurrent, multi-user input to applications through networked computers, but this approach can inhibit some aspects of the collaborative process, such as the development of mutual understanding of the shared virtual workspace. Another solution is to provide concurrent interaction on a single computer, which is now technologically feasible but most applications do not support this form of interaction. This emphasises the need for more flexible technology that can support a variety of activities, without hindering the human–human interaction that is essential for any collaborative activity.

References

Bier, E.A.. & Freeman, S. (1991) MMM: A User Interface Architecture for Shared Editors on a Single Screen. In *Proceedings of User Interface Software and Technology (UIST'91*) pp. 79–86. ACM Press, New York.

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 Conference on Educational Multimedia, Hypermedia & Telecommunications (EdMedia'99)* (eds. B. Collins & R. Oliver) pp. 587–592. AACE, Charlottesville, VA.

Hymel, S., Zinck, B. & Ditner, E. (1993) Cooperation versus competition in the classroom. *Exceptionality Education Canada*, **3**, 1–2, 103–128.

Inkpen, K. (1997) Three Important Research Agendas for Educational Multimedia: Learning, Children and Gender. In *Proceedings of Conference on Educational Multimedia, Hypermedia & Telecommunications (EdMedia'97)* (eds. T. Müldner & T. Reeves) pp. 521–526. AACE, Charlottesville, VA.

Inkpen, K., Booth, K.S., Klawe, M. & Upitis, R. (1995) Playing together beats playing apart, especially for girls. In *Proceedings of Computer-Supported Collaborative Learning (CSCL'95)* (eds. J. Schnase & E. Cunnius) pp. 177–181. Lawrence Erlbaum, Hillsdale, NJ.

Inkpen, K., 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 Computer Supported Collaborative Learning (CSCL'99)* (eds. C. Hoadley & J. Roschelle) pp. 252-259. Lawrence Erlbaum, Hillsdale, NJ.

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.

Pedersen, E., McCall, K., Moran, T. & Halasz, F. (1993) Tivoli: an Electronic Whiteboard for Informal Workgroup Meetings. In *Proceedings of Human Factors in Computing Systems (Interchi'93: Bridges Between Worlds.* (eds. S. Ashlund, K. Mullet, A. Henderson, E. Hollnagel & T. White) pp. 391–398. ACM Press, New York.

Scott, S.D., Mandryk, R.L. & Inkpen, K.M. (2002) Understanding Children's Interactions in Synchronous Shared Environments. In *Proceedings of Computer Supported Collaborative Learning (CSCL'02)* (ed. G. Stahl) pp. 333–341. Lawrence Erlbaum, Hillsdale, NJ.

Scott, S.D., Shoemaker, G.B.D. & Inkpen, K.M. (2000) Towards Seamless Support of Natural Collaborative Interactions. In *Proceedings of Graphics Interface 2000*, pp. 103–110. Canadian Human-Computer Communications Society and AK Peters Ltd., Waterloo, Ontario.

Stanton, D., Neale, H. & Bayon, V. (2002) Interfaces to support children's co-present collaboration. *Multiple Mice and Tangible Technologies.* In *Proceedings of Computer Supported Collaborative Learning. (CSCL' 02)* (ed. G. Stahl) pp. 342–351. Lawrence Erlbaum, Hillsdale, NJ.

Stewart, J., Raybourn, E.M., Bederson, B.B. & Druin, A. (1998) When two hands are better than one. Enhancing Collaboration Using Single Display Groupware. In *Extended Abstracts of Human Factors in Computer Systems (CHI'98): Making the Impossible Possible* (eds. C.-M. Karat & J. Karat) pp. 287–288. ACM Press, New York.

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 Computer-Supported Cooperative Work (CSCW'94): Transcending Boundaries* (eds. J. Smith & F. Smith) pp. 345–358. ACM Press, New York.

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 Human Factors in Computing Systems -(CHI'99): The CHI is the Limit.* (eds. M. Williams, M. Altom, K. Ehrlich & W. Newman) pp. 120–127. ACM Press, New York.

Tang, J.C. (1991) Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies*, **34**, 143–160.

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 Human Factors in Computing Systems (CHI'94): Celebrating Interdependence* (eds. B. Adelson, S. Dumais & J. Olson) pp. 44–50. ACM Press, NY.

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

Zanella, A. & Greenberg, S. (2000) A Single Display Groupware Widget Set. In *Proceedings of the Western Computer Graphics Symposium ¢00.* pp. 85–88. University of Alberta, Edmonton.