Interfaces to Support Children's Co-present Collaboration: Multiple Mice and Tangible Technologies

Danaë Stanton,[1] Helen Neale[2], Victor Bayon[3]

[1]CREDIT, School of Psychology, [2]Virtual Reality Applications Research Team,
[3] Mixed Reality Lab
University of Nottingham
University Park
Nottingham
NG2 2RD
UK
[1]Danae.Stanton@nottingham.ac.uk [2]Helen.Neale@nottingham.ac.uk [3]Vxb@cs.nott.ac.uk

ABSTRACT

This paper summarises two different approaches using technology to support young children's collaborative interaction in a classroom setting. KidPad, a 2½D drawing package with zooming capabilities, was adapted for use with multiple mice and tangible interfaces. The first section of the paper focuses on a study carried out to evaluate the effect of multiple mice on children's collaborative behaviour at a desktop computer. Positive effects of the use of two mice included symmetry of mouse use amongst pairs and a greater degree of engagement in the task. However a number of usability issues were identified when children attempted to collaborate, particular problems were faced when the shared control was taken away, and one of the users took control, for example, when navigating. Different types of working styles were also evident between the one mouse and two mice conditions. The second section of the paper describes a move away from the desktop computer towards room-based technologies. Tangible interfaces to KidPad were developed in order to facilitate shared control over actions such as navigation where difficulties had been identified in a desktop situation. The visibility of action is highlighted as a fundamental element in the support of collaboration on a larger scale. Finally, future work and the potential of these technologies in encouraging shareable co-present interaction in a real school context are briefly discussed.

Keywords

Collaboration, children, evaluation, usability, tangible interfaces, single display groupware

INTRODUCTION

Group work with young children is well established in British schools (Galton and Williamson, 1992) and research in psychology and education has consistently demonstrated that working in pairs and small groups can have advantageous effects on learning and development, especially in young children (Rogoff, 1990; Topping, 1992; Wood & O'Malley, 1996).

The role of the computer in supporting collaborative learning has been examined (Barfurth, 1995; Crook, 1994, O'Malley, 1992). Littleton (1999) suggests that the computer is not just capable of supporting collaborative behaviour, but is unique in that it can transform the way in which collaborative activity is structured. A limited number of computers in schools and an emphasis on group work in the UK school curriculum means that it is important to examine "how new technology (can) serve effectively to resource collaborative arrangements for learning?" (p.122, Crook, 1994).

Traditional computer software and hardware has been designed with only one user in mind, two users must share a mouse and control over one cursor on the screen. This may result in an unequal balance between two children collaborating in this situation. For example, Light and Glachan's (1985) study found that boys are more likely to take control of the mouse when access was limited.

The aim of the KidStory project is to develop new technologies that support small group collaboration within the classroom. The main focus of this research is to support young children (aged 6 and 7) to collaborate in the creation and re-telling of stories, using technologies specifically design for this. Over the last 3 years researchers have built up a close working relationship with teachers and children in school. This has allowed children and teachers to influence technology design using a 'participatory' or 'co-operative' approach (for more information on the design process please see Neale, in preparation, Taxen, 2001). It has also meant that the authors have been able to assess the impact of technologies, designed to support collaboration, and modify, refine and improve them to take into account usability, functionality and issues regarding the school context.

The first part of this paper describes the development and use of multiple input devices. An evaluation study has been conducted to investigate the impact of 2 mice on pairs of children's story creation.

The second part of this paper focuses on tangible interfaces to KidPad to support group learning in the classroom.

MULTIPLE MICE TO ENCOURAGE CO-PRESENT COLLABORATION

Standard computer systems are designed to support single users working alone, however, within schools it is common for pairs or small groups to work together around a computer, and for them to collaborate on a shared task. Even though two or more children may collaborate verbally, only one child at a time has control of the computer. The recognition that group work around a single display is desirable for many groups of users has led to the development of software and hardware that is designed specifically to support this. There are a number of difficulties in developing computer systems that support multiple input devices, however recently technical advances have been made in Single Display Groupware (Stewart, Bederson and Druin, 1999).

Single Display Groupware (SDG) allows two or more co-located users to interact with a computer system simultaneously whilst feedback is provided via a single display screen. SDG therefore enables all participants to input to the same piece of computer-based work. This type of software could be used to support a number of different situations where two or more people are gathered around a computer, all commenting on, interacting with, or editing the same artefact.

Very few studies have been conducted to examine the effect of multiple input devices on collaborative interactions and so little is known about how they may influence behaviour. Reported here is a summary of the studies that have examined SDG use.

Inkpen, Booth, Gribble and Klawe (1995) examined children's use of commercial computer games, and found that they were more motivated when playing together on a single machine, as opposed to playing side by side on computers or by themselves. The effect of giving each user an input device, even if only one could be active at a time was then examined and significant learning improvements were found (Inkpen, Booth, Klawe and McGrenere, 1997). Preliminary results from a study of pairs of students working together using SDG to complete a problem solving task indicate that children using two mice demonstrate higher levels of activity and less time off task (Inkpen, Ho-Ching, Kuederle, Scott and Shoemaker, 1999).

Stewart, Raybourn, Bederson and Druin (1998) observed that children with access to multiple input devices seemed to enjoy an enhanced experience, with the researchers observing increased incidences of student-student interaction and student-teacher interaction as well as changing the character of the collaborative interaction. The children also seemed to enjoy their experience more, compared with earlier observations of them using similar software on standard systems. The availability of an input device for each child also suggests that no one child would be able to monopolise the task (Stewart et al, 1999). Stewart et al (1999) do however recognise that some negative effects on behaviour may occur with SDG use. For example, task completion may take longer, as no one user can direct the product, also the opportunity to work in parallel may mean that users in fact collaborate less than when they had to share one form of input.

Abnett, Stanton, Neale and O'Malley (2000) found some gender effects when using two mice with KidPad. Interaction with two input devices led to greater equity between gender pairings, while interaction when using one mouse led to poorer performance in mixed gender and male gender pairs.

Thus there is some evidence that the use of multiple input devices improves motivation, effectiveness of task completion (through parallel or co-operative work), equity of activity and time on task.

In some cases SDG applications have been specifically designed to *force* or *encourage* users to collaborate. In one study, multiple users were each given control of one aspect of an activity and therefore had to work together in order to reach their goal (Bricker, Baker and Tanimoto, 1997). Rather than forcing users to carry out actions, some SDG applications are designed to encourage people to actively take part in group activities (Sugimoto, Kunsunoki, and Hashizume, 2000) or to enhance the results of activities carried out when these are achieved by working collaboratively with others (Benford, Bederson, Akesson et al, 2000).

One of the major goals of the first year of the KidStory project was to develop technologies that supported collaboration around a desktop computer. As well as supporting multiple mice, software was developed to encourage children to work together. Two pieces of software 'KidPad' and the 'Klump' were developed with functionality's designed to encourage collaboration (Benford et al, 2000). Only KidPad is elaborated upon here as more extensive studies in schools have been undertaken with it.

KidPad is a collaborative authoring tool designed for children (Druin, Stewart, Proft, Bederson and Hollan, 1997). KidPad enables children to draw, edit and write stories using links to connect elements of their story. They can then use these links to 'zoom' to objects that may not appear within screen shot.

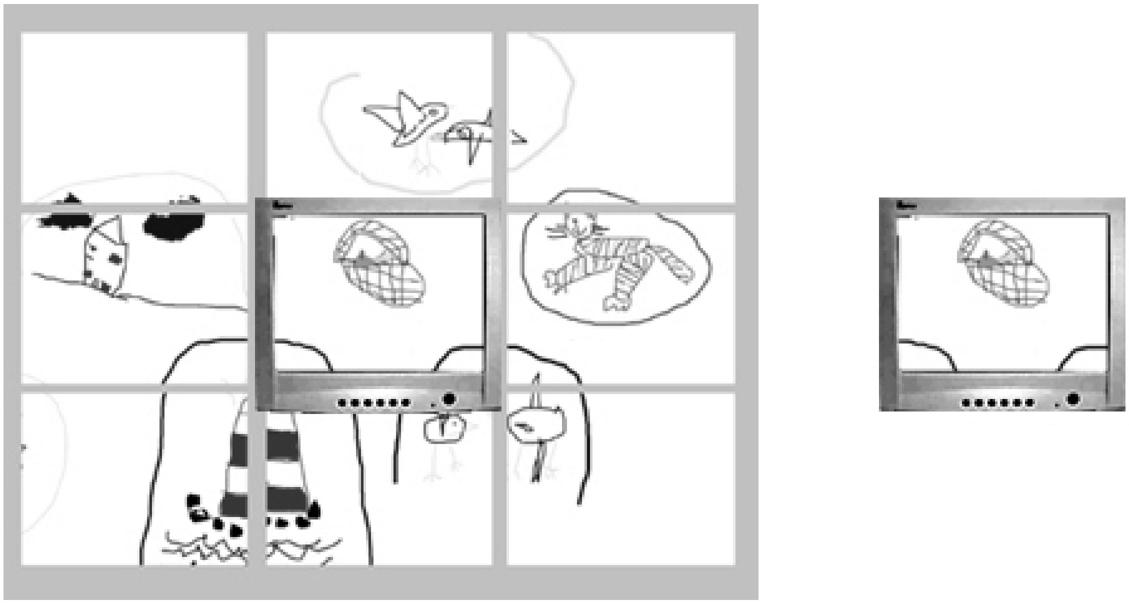

Figure 1. A typical KidPad story created by a class of 7-year-olds. Only one part of the story is visible. By zooming in/out or navigating left/right or up/down it is possible to view the other parts of the story or access blank space to create more content. In this case at that level of zooming it is only possible to view 1/9 of the graphical representation.

Collaboration with multiple input devices

An observation study was carried out where pairs of children were asked to complete a storytelling task in KidPad using either one or two mice. From the results of previous studies examining multiple mice use, as well as informal observations of KidPad use, it was hypothesised that the use of multiple mice would produce less off task behaviour and also greater synchrony of mouse use in line with Inkpen et al's (1999) findings. However, the study also aimed to explore, in detail, the effect of multiple mice on collaborative dialogue and computer-based interactions. Analysis was facilitated by mixing video capture of both the computer screen, and the children, enabling the development of a coding scheme (see figure 2). A detailed account of how the study was carried out and the outcomes in terms of collaborative behaviours can be found in Stanton and Neale (in preparation).

Method

Twelve pairs of children aged between 6 and 7 years used KidPad to carry out a creative task. Six of the pairs carried out the task using KidPad with only one mouse while the remaining six pairs used two mice. Children chose a classmate who they wanted to work with. The groups were balanced in terms of ability and gender. The children who took part in the study were familiar with the researchers who had been working in with the school for the previous eighteen months. They were also familiar with KidPad and its features.

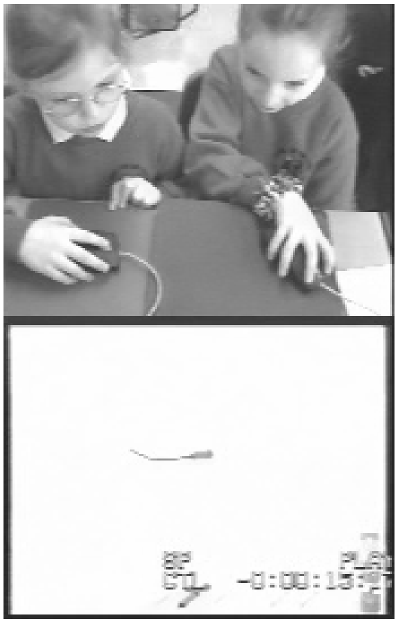

Figure 2. Video capture of the children and on screen activity enabled analysis of talk and actions.

The study took place in the corner of the classroom during an academic lesson, usually English literacy. The children were introduced to the task and told that they were to use KidPad to recreate a poem. The poem used was 'Twinkle, Twinkle chocolate bar', a poem they had previously read in class. The children were encouraged to work together and were told that their KidPad story was to be presented to their teacher on completion.

Results

For the entire period of computer use, children's activities were recorded to identify whether they were active and on task; inactive but still on-task; or off task.

In the one mouse condition 42% of the time was spent actively drawing, writing or creating their story in comparison to 73.30% of the time with 2 mice. In the one mouse condition children were non-active (involved in the task, either watching what their partner was doing, instructing, or commenting, but not actually using an input device) 48.28% of the time while in the two mice condition the children were non-active 17% of the time.

Non attentive behaviour (such as looking away from the computer screen) was found to be low for both the one mouse and the two mice conditions 3.42% and 0.9% respectively. However in the one mouse condition there were cases where children were non-attentive for 9% and 16.22% of the time.

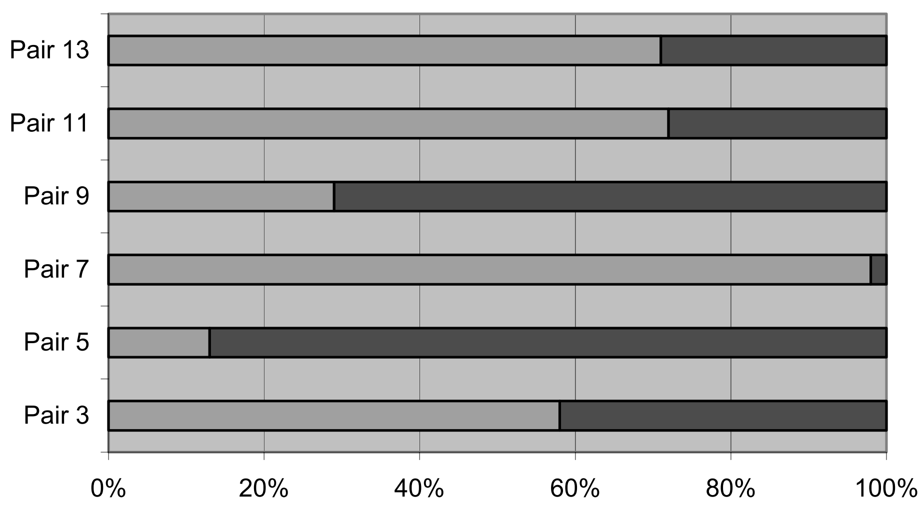

Figure 3. Distribution of mouse use between left-hand side and right-hand side (1 mouse)

Figure 3 and Figure 4 illustrate the distribution of active mouse use between the left-hand and right-hand partners. In the 2-mouse condition input was fairly symmetrically distributed. However in the one mouse condition the patterns are more asymmetric, with individuals dominating. For example, in pair 7 one of the pair has the mouse for 98% of the total task time.

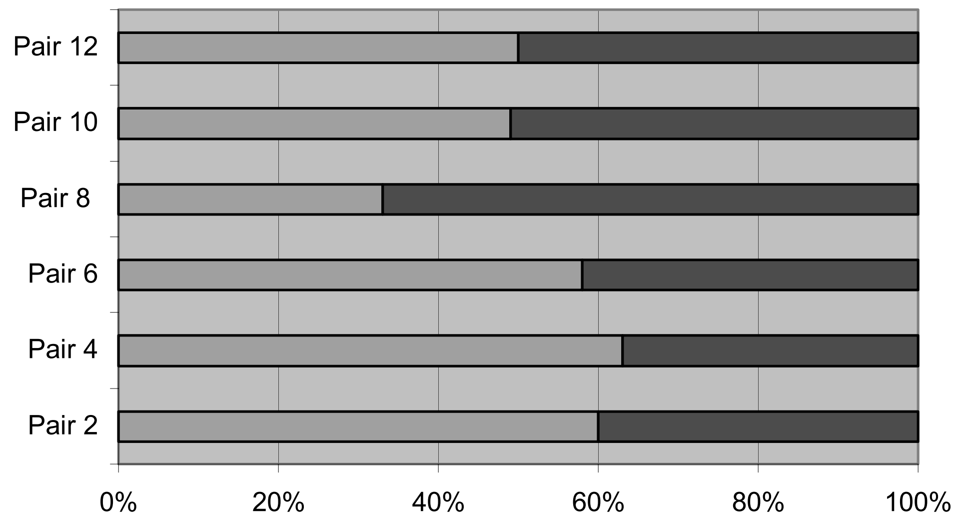

Figure 4. Distribution of mouse use between left-hand side and right-hand side (2 mice)

Access to the mouse does not necessarily portray the full picture of collaborative behaviour and it is important to look for indicators 'beneath the surface' to find out who is controlling the collaborative actions and contributing to the production of ideas (Cole, 1995). The person in control of the mouse may be physically active but not psychologically active. A more detailed analysis of the interactions between the pairs was carried out (for a more detailed account see Stanton and Neale, in prep). Previous work in this area has focused primarily on talk and less on actions, in the study presented here actions were analysed alongside talk as they often indicate important parts of the interaction such as acceptance of ideas or children may input ideas directly onto the computer without verbalising them.

Collaboration Networks have been used to code and represent collaborative interactions around the computer. This method was developed specifically to address some of the deficiencies in existing methods in the analysis and presentation of complex collaborative processes. Both verbal and computer-based interactions are recorded and visually represented in terms of the temporal and evolutionary path that the interaction has taken (Neale and Stanton, in press).

The exploration of collaborative interactions amongst pairs using either one or two mice identified a number of patterns of collaborative behaviour. Many of the differences between collaborative styles were due to individual differences between pairs; however, the authors did recognise certain styles common to both one mouse and two-mouse use. When two mice are available to the pair, they tend to work co-operatively, they create computer representations on their own, usually verbalising what they are doing, but are not encouraged to discuss aspects of the task. There is noticeably less verbal reciprocity between the partners when they have a mouse each.

When one mouse was available some pairs demonstrated high levels of collaborative activity, where ideas were discussed with contributions from both partners before they were implemented on the computer. Other pairs demonstrated low levels of collaborative interaction, where one partner dominated the work, leading to an asymmetric distribution of idea input and creation.

The evaluation study found some advantage of using 2 mice such as the symmetry of input afforded by 2 mice, the higher levels of engagement with the task and increased productivity with more overall time for creation. These results support work by others such as Inkpen et al (1999). However a detailed examination of the interaction taking place also uncovered different styles of behaviour attributed to the number of mice used and formally confirms some of the points raised by Stewart et al (1999). The use of 2 mice seems to encourage a co-operative and parallel style of working while we have found considerably more elaboration/extension of ideas taking place before these ideas are implemented on the computer when pairs share one mouse. On occasions when a pair has one mouse, low levels of collaborative behaviour have been observed, with one partner dominating and directing.

Multiple input devices at the desktop have been seen to facilitate pairs of children in actively working on a shared task at the same time. There are however a number of limitations to the ability of this type of technology to support small group work. Firstly the physical size of the output device means that it could never support more than a few users working simultaneously. At most 3 or 4 children could sit around and input to a single desktop computer. A number of usability problems related to multiple users have been identified from observing this technology in use. Most of the actions facilitated by the software enabled two or more users to work at the same time, a few of the actions only allowed one partner to carry them out, for example, navigation, often disabling or disrupted their partner from carrying on with their task. This often caused confusion and frustration.

TANGIBLE TECHNOLOGIES TO ENCOURAGE CO-PRESENT COLLABORATION

In this section tangible technologies are defined and reasons why they may be beneficial in terms of collaboration are outlined. One particular interface 'the magic carpet' is discussed, and some informal observations of use are detailed.

The approach taken within years 2 and 3 of the KidStory project to interface development has mostly focused on physical and tangible interfaces (see Stanton, Bayon, Neale et al, 2001). Physical in that the interaction is based on movement and tangible in that objects are to be touched and grasped.

In HCI research there has been a general move towards, and much support for, the development of tangible and mobile interfaces to facilitate computer use (e.g. Norman, 1999). Many of the types of interfaces that are being created support socially based activities. Research is being carried out using tangible and physical interfaces for children's play and learning (see Bobick, Intille, Davis et al, 2000; Ryokai and Cassel, 1999; Strommen, 1998). Other authors have developed devices to aid children's computational skills in a collaborative context, for example see 'curlybot' (Frei, Su, Mikhak and Ishii, 2000) and a study by, Kynigos and Giannoutsou (2001) which used GPS to examine spatial and orientation concepts when groups of 7 year olds carried out collaborative cartography. In spite of these recent developments, little is known about the influence of tangible technology on collaborative learning, particularly with children in a school environment.

In the KidStory project tangibles have been developed as interfaces that inherently support small group collaboration amongst young children. Much of this development was also based around the KidPad software, described in the above sections. When working in a school it became clear that if the teacher was to be involved in using the technology with a sub-set of her class, then the rest of the class needed to be able to participate in the experience in some way. Replacing a standard monitor with a large projected screen helped to accomplish this. A number of different input devices were used to allow multiple users to interact with KidPad carrying out different functions, for example, creating a scene, creating a sound, and navigating, were all carried out using different input devices. This section will focus on one particular input device 'the magic carpet'.

The Magic Carpet is a collaborative tangible interface based on 12 floor sensors, with 3 sensors arranged on each side to create a square. KidPad is usually projected onto a large screen in front of the carpet, providing a display that can be clearly seen by groups of users. Children interact with the Magic Carpet by standing on its pressure sensitive sides. This input device allows users to travel forwards into the KidPad scene, backwards to zoom out of the scene, and left and right (a separate input device was used to travel along a third axis, up and down). To travel forwards, users stand at the front of the carpet; to travel backwards they stand at the back, and so forth. The number of sensors activated at any time affects the viewpoint in KidPad. Multiple sensors may be activated at the same time altering the way in which the user navigates through KidPad. It is possible to, for instance, zoom in and move right by standing at the front and the right side of the carpet and activating the sensors on those sides of the magic carpet, or zoom in faster by standing and activating all 3 of the sensors at the back of the magic carpet.

The design of the magic carpet meant that interaction was scaled up, allowing larger groups of children to interact with the technology simultaneously. Sensors were widely distributed about the carpet, meaning that many children could use the carpet at the same time, in fact benefits were found by multiple users working together to navigate.

A key factor of moving technology into a larger space, providing room for objects to become organised spatially, is that the visibility of other people's actions is increased. Initially the magic carpet was used to re-tell stories created on a desktop version of KidPad. Informal observation of these sessions indicated that navigation using the magic carpet drew children's attention to the spatial features of KidPad and in contrast to the desktop a considerable amount of time was spent navigating. Navigation became a collaborative activity rather than a one-person process. The physical size of the carpet and the visibility of actions meant that group interaction was encouraged as well as navigation. The set-up enabled all of the group members to contribute and they worked as a team.

Figures 5, 6 and 7 illustrate a group of children using the magic carpet to retell a story to their peers. In the first image the children are all on the left hand side of the carpet moving the image on screen to the left. In the middle image one of the children is indicating that they are going in the wrong direction to get their pictures. The third image illustrates the move of all interactors to the right hand side of the carpet. By all working together to navigate they are moving faster than one child carrying out this action alone.

Figure 5 Children move the viewpoint by standing on the left-hand side of the

Figure 6 One child realises that they need to travel in the other direction and points in the direction she wants them

Figure 7 All of the children move over to the right hand side of the carpet to move the viewpoint in the other direction

These findings are only informal observations, however, an in depth evaluation of a spatially distributed tangible set-up has recently been carried out and is currently being analysed (see Stanton et al., in prep). Collaboration on a story creation task using tangible technologies is examined in terms of its ability to encourage and support collaborative behaviour. Four children used a variety of the tangible technologies, including the magic carpet over three sessions. The technology consisted of a large display in which they could input pictures (using PDA's, a webcam and a scanner) and sounds (using RFID tags) and navigation using an arrangement of sensors 'the magic carpet'. The children could then retell their story using bar-coded images and sounds. Pending results from this study will provide new information about how children collaborate when using tangible interfaces.

DISCUSSION

Until recently most of the technology developed to aid computer assisted learning was designed with one user in mind regardless as to the activities around the computer.

O'Malley (1992) presents three classifications of the role of the computer in collaborative settings. The third of her classifications is termed 'Learning mediated via the computer' where she describes the computer as a tool, which 'augments' collaborative learning with the technology designed for pair or group activities. With careful structuring of the activity, desktop KidPad with 2 mice fits neatly within this classification. However O'Malley suggests that there is probably a continuum of roles rather than a strict categorisation and we would suggest that tangible technology is further along that continuum. While asynchronous interaction is reported to allow reflection and reaction time, the visibility of actions when using tangible technologies allows multiple users to carry out synchronous interaction while maintaining awareness of the collective collaborative action.

Although there has been a rapid advance in the design and use of technologies, such as SDG and tangible interfaces, formal evaluation is still limited. Here we have outlined ways in which these two types of technology have been used to encourage collaboration in educational settings. A formal study evaluating the use of one or two mice indicates that two mice produce a more even symmetry of use and higher levels of task engagement. However mouse use reflects very different working styles with two mice favouring co-operative work and 1 mouse favouring more collaborative working styles. The potential of tangible interfaces for group activities in the classroom has been discussed; preliminary observations identify that the physicality of inputs, the spatial distribution of the set-up and the visibility of actions are important factors in aiding collaborative behaviour. Ongoing work aims to evaluate children's collaborative learning with tangible technologies.

The children using the technologies described in this paper have all been between 6-7 years old. Interaction with tangibles may be well suited to very young children because of their physicality, as mouse co-ordination skills or verbal ability would not limit children. One of the teachers involved in the project over the last 3 years stated that a major advantage of the tangible technologies was that the less able students (in terms of reading and writing ability) were able to express themselves.

Desktop KidPad and variations of KidStory tangible technologies continue to be used within classrooms, in pairs, small groups and for whole class sessions. The success of this integration is summed up in the Ofsted report (school inspection board in the UK) who state under "Good teaching, alongside a vibrant and rich curriculum, means that learning is effective: - Visitors to school add an extra dimension to the whole curriculum. An excellent example is the involvement of the Kidstory team from Nottingham University. The project aims to encourage the pupils to work collaboratively together, and it is very successful. It has been in place for three years, giving the pupils an opportunity to use a range of new technologies for communication. In the lesson seen pupils worked very effectively to create different parts of their story, using new technology."

ACKNOWLEDGEMENTS

This work has been conducted as part of the KidStory project funded by ESPRIT (#29310). The authors acknowledge support from project partners at CREDIT, VIRART and CRG University of Nottingham, SICS and KTH in Sweden and The University of Maryland, USA. We would particularly like to thank Ben Bederson for KidPad and his continuing enthusiasm in developing it (to download KidPad please see www.kidpad.org) and Camilla Abnett for her help with data collection. Thanks also to the teachers and children at Albany Infant School, Nottingham for their collaboration in this work.

REFERENCES

Abnett, C., Stanton, D., Neale, H and O'Malley (2001) The effect of multiple input devices on collaboration and gender issues. In the *Proceedings of European Perspectives on Computer-Supported Collaborative Learning (EuroCSCL)* 2001, March 22-24, Maastricht, the Netherlands. p.29-36.

Barfurth, M.A. (1995) Understanding the collaborative learning process in a technology rich environment: The case of children's disagreements. *In the proceedings of CSCL 1995.*

Benford, S., Bederson, B., Åkesson, K.-P., Bayon, V., Druin, A., Hansson, P., Hourcade, J., Ingram, R., Neale, H., O'Malley, C., Simsarian, K., Stanton, D., Sundblad, Y., & Taxén, G., Designing storytelling technologies to encourage collaboration between young children. *CHI 2000* pp. 556-563.

Bobick, A., Intille, S., Davis, J., Baird, F., Pinhanez, C., Campbell, L., Ivanov, Y., Schutte, A., & Wilson, A., The KidsRoom: A perceptually-based interactive and immersive story environment. *Presence: Teleoperators and Virtual Environments,* **8**(4), 367-391, 2000.

Bricker, L. J., Baker, M. J., & Tanimoto, S. L. (1997). Support for cooperatively controlled objects in multimedia applications. Paper presented at the *Proceedings of Human Factors in Computing Systems (CH'97)*, Atlanta, GA

Cole, K.A. (1995) Equity issues in computer based collaboration: Looking beyond surface indicators, *In Proceedings of CSCL 95*, http://www-cscl95.indiana.edu/cscl95/cole.html

Crook C. (1994) Learning within peer collaborations. In Charles Crook, *Computers and the Collaborative Experience of Learning*. Routledge, London.

Druin, A., Stewart, J., Proft, D., Bederson, B., & Hollan, J,. KidPad: A design collaboration between children, technologists and educators*.* *CHI97* pp. 463-470.

Frei, P, Su, V., Mikhak, B., and Ishii, H. (2000). Curlybot: Designing a New Class of Computational Toys. *In Proceedings of Human Factors in Computing Systems (CHI 2001)* ACM Press, pp.129-136.

Galton, M. and Williamson, J (1992) *Group work in the Primary classroom.* Routledge, London

Inkpen, K., Booth, K.S., Gribble, S.D. and Klawe, M. (1995). Playing together beats playing apart, especially for girls. *Proceedings of CSCL'95*

Inkpen, K. M., Booth, K. S., Klawe, M., & McGrenere, J. (1997). The Effect of Turn-Taking Protocols on Children's Learning in Mouse-Driven Collaborative Environments. *In Proceedings of Graphics Interface (GI 97)* Canadian Information Processing Society, pp. 138-145.

Inkpen, K.M., Ho-Ching, W., Kuederle, O., Scott, S.D. and Shoemaker, G.B.D. (1999). "This is fun! We're all best friends and we're all playing": Supporting children's synchronous collaboration. *Proceedings of CSCL 99*

Kynigos, C. and Giannoutsou, N. (2001). Seven year olds collaborating to construct a map using GPS and space representation software. In the Proceedings of *European Perspectives on Computer-Supported Collaborative Learning (EuroCSCL)* 2001, March 22-24, Maastricht, the Netherlands. p.364.

Littleton, K. (1999). Productivity through interaction: An overview. In K. Littleton and P. Light (Eds.) *Learning with Computers: Analysing productive interaction.* Routledge. Londonp.179-194.

Light, P. & Glachan, M. (1985) Facilitation of individual problem solving through peer interaction, *Educational Psychology,* **5**, 3-4, 217-225.

Neale, H.R. & Stanton, D. (In press) Evaluating verbal and computer-based interactions using collaboration networks. *Computer Support for Collaborative Learning. (CSCL) 2002*. Boulder, Colorado, USA. January 7th-11th.

Neale, H. Stanton, D. (in preparation) Supporting co-present creative tasks: design issues for Single Display Groupware

Neale, H., Stanton, D., Cobb, S. (in preparation) Development of children's collaborative storytelling technologies: Working with users in schools.

Norman, D. (1999) *Invisible Computer,* MIT Press.

O'Malley, C. (1992) Designing computer systems to support peer learning, European Journal of Psychology of Education, *7, 4, 339-352.*

Ofsted report (2001) www.ofsted.gov.uk/inspect/index.htm no. 194367

Rogoff, B., *Apprenticeship in Thinking: Cognitive Development in Social Context*. New York: Oxford University Press, 1990.

Roschelle, J and Teasley, S.D. (1991) The construction of shared knowledge in collaborative problem solving. In O'Malley (Ed) *Computer Supported Collaborative Learning*, Springer Verlag, Berlin. 67- 97.

Ryokai, K. & Cassel, J., Computer Support for Children's Collaborative Fantasy Play and Story Telling, *CSCL'99*, 1999.

Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., Wilson, J., Pridmore, T., & O'Malley, C. (2001). Classroom Collaboration in the Design of Tangible Interfaces for Storytelling. *In Proceedings of Human Factors in Computing Systems (CHI 2001)* ACM Press, pp. 482-489.

Stanton, D., Abnett, C., Bayon, V., Cobb, S. and O'Malley, C. (In prep). The use of Tangible Interfaces to encourage small group physical and social collaboration.

Stanton, D and Neale N. (in prep) Collaborative behaviour around the desktop: The effect of multiple mice on children's talk and interaction.

Stewart, J., Raybourn, E. M., Bederson, B., & Druin, A. (1998). When two hands are better than one: Enhancing collaboration using single display groupware. Paper presented at the *Proceedings of Extended Abstracts of Human Factors in Computing Systems (CHI'98)*.

Stewart, J., Bederson, B., & Druin, A. (1999) Single display groupware: A model for co-present collaboration*.* *CHI99* pp. 287-288, 1999.

Strommen, E., When the interface is a talking dinosaur: Learning across media with Actimates Barney. *CHI98* pp. 288-295, 1998.

Sugimoto, M., Kunsunoki, F., & Hashizume, H. (2000, December 2-6, 2000). Supporting face-to-face group activities with a sensor-embedded board. Paper presented at the *Computer Supported Cooperative Work*, Philidelphia, Pennsylvania

Taxen, G., Druin, A., Fast, C., & Kjellin, M. (2001). KidStory: a technology design partnership with children. *Behaviour and Information Technology, 20*(2), 119-125

Topping, K., Cooperative learning and peer tutoring: An overview. *The Psychologist,* ***5***, 151-157, 1992.

Wood, D., & O'Malley, C., Collaborative learning between peers: An overview. *Educational Psychology in Practice, 11*(4), 4-9, 1996