Classroom Collaboration in the Design of Tangible Interfaces for Storytelling

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ABSTRACT

We describe the design of tangible interfaces to the KidPad collaborative drawing tool. Our aims are to support the re-enactment of stories to audiences, and integration within real classroom environments. A six-month iterative design process, working with children and teachers in school, has produced the "magic carpet", an interface that uses pressure mats and video-tracked and barcoded physical props to navigate a story in KidPad. Reflecting on this process, we propose four guidelines for the design of tangible interfaces for the classroom. (1) Use physical size and physical props to encourage collaboration. (2) Be aware of how different interfaces emphasize different actions. (3) Be aware that superficial changes to the design can produce very different physical interactions. (4) Focus on open low-tech technologies rather than (over) polished products.

Keywords

Tangibles, children, storytelling, participatory design

INTRODUCTION

We are developing collaborative storytelling technologies for children aged 5-7. A key focus of our research is on developing technologies to be used in schools and also intensively working with children and teachers within these schools during design and development.

Learning in the classroom, particularly at these ages, is fundamentally a social activity. While some individual activities occur, much of the class time is taken up with small group or whole class teaching. In the UK primary school (ages 5-11) context, for example, one class session may involve several re-configurations of individual, small-group and whole class teaching. This is particularly the case for classroom storytelling activities with the implementation of the UK National Literacy Strategy [6], but may be common to many other classroom contexts.

Research in psychology and education has demonstrated clear benefits for children of collaborative learning activities in a variety of domains [19, 23]. There is also an emerging body of research demonstrating the value of computer support for collaborative learning [5, 14, 17]. However, collaboration and learning will only occur if the technology is designed to fit within the context of use for which it is intended. Otherwise, the interface may actually be a barrier to learning [16].

We take seriously the physical, social and organizational constraints of real classroom contexts in our approach to design. We wish to develop technologies that not only support existing classroom storytelling activities but also augment them in beneficial ways without disrupting the normal classroom organization. This paper describes lessons learned from the design of tangible interfaces in order to support whole class storytelling activities within one of the schools involved in our project – a class of 6-7 year olds from a primary school in the UK.

We have extended The University of Maryland's KidPad, a shared 2D drawing tool that allows children to bring their stories to life by zooming between drawing elements [8]. Stories are created by drawing story objects using various tools such as crayons and paintbrushes anywhere on an infinite 2D drawing surface and linking these elements together to create sequences of events. Links are used to zoom around the drawing plane and to zoom into objects to reveal more detail [2, 8]. KidPad had previously been extended to support multiple mice [22] combined with a technique called 'tool mixing' [2] in order to encourage shoulder to shoulder collaboration. By this we mean that when two (or more) children use 'mixable' tools together, the tools give enhanced functionality. For example, in the shared version of the KidPad drawing tool, children can use different colored crayons to draw in the usual way. But when two crayons are used at the same time they enable children to create a filled area together [2, p. 561].

KidPad has recently been taken up in a UK school and used independently by a teacher as part of mainstream teaching. There are now plans for all of the classes in this school to use it next year. Despite its successful adoption by the school, early experiences have raised a number of important

problems that need to be addressed in the further development and educational use of this technology. Two main ones are as follows. First, children find it difficult to use some of the features of KidPad – especially zooming and navigation, probably due to the need to use mice to manipulate the on-screen tools. Second, KidPad is not currently easy to integrate with whole class storytelling activities that may involve large groups of children and incorporate physical artifacts made by the children in traditional materials (e.g., drawings and models).

We describe the design of an interface to KidPad to address these problems; replacing the laptop configuration with a combination of different tangible group interaction techniques.

DESIGN GOALS AND MOTIVATIONS
The following design requirements and constraints were derived from our experience of using the version of KidPad with multiple mice in the classroom.

Navigation: Navigation in KidPad on laptops raised certain problems. The children found it hard to create and follow links using the mouse to manipulate the link tool – especially since this sometimes required simultaneous use of a key to zoom to another part of the drawing. Navigating in storytelling was also difficult using the keyboard to zoom or the mouse to find and follow links. More fundamentally, it wasn't obvious how to support the collaborative use of these features in a 'natural' way.

Group size: KidPad on laptops seemed to work well for small groups (2-3 children) but not so well for larger groups. We needed an alternative approach to scale up to support collaboration in larger groups, potentially involving the whole class.

Story retelling versus story creation: KidPad has so far been focused mainly on supporting story creation. We wished to extend its capability to support story retelling and the *performance* or enactment of stories to watching audiences.

Integration with traditional materials: In taking account of the physical classroom context, we wished to create technologies that made use of, and integrated traditional materials (e.g., paper, cardboard models, costumes). In this way the technology could be used as part of larger classroom projects, rather than as an isolated activity.

Configurability: Our aim was to design technology that could be easily tailored by the children and teachers, and that could easily be re-configured to suit different activities and physical settings.

In extending KidPad to meet these requirements, we have adopted an approach that is *physical* and *tangible*. By physical we mean that it is movement-based. By tangible we mean that it involves graspable and touchable objects [8]. Physical and tangible interaction is important in this context because:

- Children's collaborative activities in both play and school involve physical interactions with spaces, objects and each other.

- Support for larger groups implies moving beyond conventional sized screens and desktop devices.

- Story retelling involves some element of theatre or performance – this requires expressive ways of rendering interaction *visible* to an audience.

- Existing classroom materials are tangible (e.g., crayons, paper, cardboard, etc) and we aim to integrate with these.

Of course, other researchers have been exploring physical and tangible interfaces for children's play and stories – for example, MIT's KidsRoom [4], Triangles and 'strings' [10, 18], Curlybot [11], Ryokai & Cassell's StoryMat [20] and StoryRooms [1], among others. A defining focus of our work is on designing for group use in real classrooms. We wish to avoid creating 'special' spaces but work instead with existing classroom spaces and materials, allowing the children to create their own stories, to tell them to audiences, and to integrate them into other classroom activities.

THE DESIGN OF GROUP TANGIBLES
An intensive series of user centred design sessions focused on the development of tangible interfaces for group navigation through stories created in KidPad. The design team consisted of a group of researchers with expertise in the areas of psychology, human factors and computer science, working alongside one teacher and a class of twenty-eight six to seven year olds.

Previous work has reported methods and philosophies for the involvement of children in the design and development of new technologies [7]. However, most of this research has been limited to small groups and is not set in a real school environment. The process described in this section adapts and extends these methods to work within a real school context.

An iterative design process was followed. Group discussion and brainstorming were used to initiate and provide comment on design ideas. The ideas were documented throughout this process by way of observer note taking and children's journal entries. Theme Based Content Analysis (TBCA) was used in the analysis of journal entries [15]. This is a method of hierarchically clustering raw data from initial design suggestions into higher order thematic units. Results and observations from school-based sessions were discussed at design planning meetings from which technical development of prototypes emerged. Further school-based sessions reviewed children's reactions to these prototypes and observation results were again presented at design planning meetings. This process continued in an iterative cycle. This aspect of our research was completed over a 6-month period, involving ten school sessions each lasting 2-3 hours. Progression through these sessions can be defined within three general phases of development.

Phase 1: Thinking beyond the desktop

In the first phase (sessions 1-4) it was necessary to introduce the children to the concept of 'tangible computing'. They had already demonstrated their ability to work as design partners with our project team in developing KidPad tools for collaborative story creation; now we wanted to expand their ideas beyond the limits of the standard desktop or laptop computer, considering new means of collaborative story telling. Brainstorming and the building of low technology models were used as a means of capturing the children's ideas. In almost all cases, the children did not suggest using traditional computer interfaces such as the keyboard and mouse but described direct interface methods such as talking to the computer or touching 'hot spots' to effect change in the story.

The children created a simple story about a frog in KidPad (as described earlier) and were asked to think about how they could re-tell their story. A visit to the researchers' laboratory presented a series of very simple prototypes, originating from adult researcher brainstorming sessions and adapted to work with some story material the children had created as a class. For example, a paintbrush and colored pots were used to re-color objects within the story; a carpet was used to move around the story using whole body movement. The children interacted with these items and conducted a brainstorming session to further develop some of their own ideas.

These first prototypes were created from dismantled keyboard keys separated from the keyboard, and embedded within different objects and materials (e.g., within the paint pots or under the carpet). The keys were hidden, and the necessary actions to interact with the prototypes, were mapped to more natural every-day actions, and could be performed with hands and body. The use of very simple, accessible and affordable input devices allowed researchers to make, experiment and remake these prototypes during the following phases.

Phase 2: Refinement of prototypes

Further school-based sessions identified the focus for technical development as being navigation methods to aid re-telling of a story created in KidPad. An important component of the story-telling environment highlighted by the children (suggested by 13 out of 23 children independently) was the use of a large display screen. This was easily achieved via a projection screen and required no further technical development.

Three main technologies were subsequently developed: a 'magic carpet' that enables collaborative navigation, gesture recognition through video capture that provides movement in the vertical plane, and the use of barcodes attached to objects for direct navigation.

The Magic Carpet

The 'magic carpet' comprises a number of pressure sensors placed under a carpet. These kinds of sensors are commonly used to control automatic doors and are cheap and widely

available. Standing on a sensor affects a control input to move the observer's viewpoint around the KidPad environment. The first prototype of the magic carpet had only two sensors (for left and right) and these were covered with a piece of furry material.

Following positive feedback, this navigation device was further developed and taken back to the school in an enlarged and improved form. Eight sensors were now located around the carpet to improve its navigational capability and to enable more children to work together. The sensor positioning in the first version is shown in figure 1 and the carpet itself is shown in figure 2 (color plate). Standing on either of the sensors at the front of the carpet (facing the projection screen) would cause the viewpoint to zoom in to the drawing. Standing on those at the back would zoom out and on those at the sides would pan the viewpoint left and right. Multiple sensors could be triggered at a time, either by several children or by one child using several limbs. In this case the sensor inputs were summed to determine the resulting action. Triggering both front sensors would move forwards faster. Triggering one front and one side resulted in a diagonal movement (a combination of zoom and pan). Triggering one front and one back resulted in no movement.
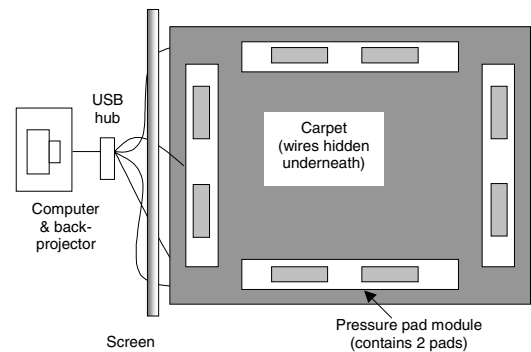

**Figure 1: layout of the second prototype (8 sensor pads)**

Figure 2: second prototype magic carpet with rectangles to show positions of sensor pads (see color plate on page 557)

The researchers observed that children in the school used the carpet collaboratively to travel diagonally and faster in one particular direction as noted above. The children remarked that they also wanted to be able to travel vertically up and down.

The next design planning meeting focused on a number of issues concerning the design of the carpet: the number of sensors required; sensor positions; size of sensors; size of carpet; axis of travel and direction of travel. Additional issues that would influence design decisions were also discussed: how many children should be able to use the carpet at once; how to enable effective collaboration; size of classroom; intuitiveness of metaphor; ease of transport/set up; what type of story telling the carpet could be used for? Space was key to this discussion as it imposes constraints; available space within the classroom determined the size of the carpet, and therefore the number of sensors that could be used.

In order to better support collaboration it was decided that a larger carpet with more sensors placed around its edges would be built. The new configuration used 3 sensors per side (12 sensors in all) arranged as shown in figure 3 so as to meet the following two requirements. As before, two children using the sensors on one side should be able to move faster than one so as to encourage collaboration (implies multiple sensors per side). A single child should be able to use the carpet on their own; they would naturally expect to stand at the center of a side in order to move (implies use of an odd number of sensors). The minimum number of sensors that meets both requirements is three.
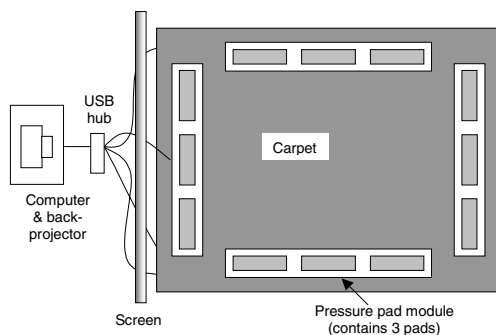
Figure 3: layout of the third prototype (12 sensor pads)

The next school session focused on the appearance of the magic carpet. Colored rectangles were placed above the pressure sensors so that children could easily see where to stand in order to move. This seemed to be effective as the children could instantly locate the sensors. However, some of the children repeatedly jumped on the colored rectangle in the hope that this would make the carpet move faster (which may also have been encouraged by the short sharp sound that was activated once the sensor had been pushed). Sixty five percent of children (15 out of 23 suggestions collected) asked for arrows to be placed on the magic carpet to indicate the direction of travel. This design idea was followed up and

presented to the children at the next school session. It dramatically changed the way in which the children interacted with the carpet. Instead of jumping with both feet on to the squares, the children carefully placed one foot onto an arrow. This meant that they usually did not put enough weight on the arrow in order to move in the environment, and subsequently did not understand why this action did not have the expected effect. In short, it appears that apparently superficial changes to the appearance of the carpet resulted in quite different physical interactions.

Figure 4: the design of the sensor pads for the third prototype magic carpet (see color plate on page 557)

Figure 5: third prototype of the magic carpet with mats around the outside edge only (see color plate on page 557)

Our most recent design incorporates features to make the carpet easier to deploy within a classroom and to integrate with other activities. The carpet has a modular design. Underneath are the pressure pads, grouped into blocks of three and encased in plastic so as to be rugged (figure 4). These blocks can be positioned on the floor as required. If space is available (the carpet needs to be used in a variety of rooms from crowded classrooms to large halls), a larger

carpet can be created with room at the center for performers or a small audience. If space is tight, the carpet can be made smaller. The blocks might even be laid out in different patterns, in rows, in a long line, or in a star, to change the style of interaction. Different materials can be laid over the pads. Later sessions in the schools used rubber mats as shown in figure 5 as these, like the blocks, are easy for one teacher to move on her own and are easy to store (important factors in a classroom where the carpet may be packed away between uses). Another possibility would be to cover the sensors with paper and then a protective transparent plastic sheet. The children can then paint the paper in order to tailor the carpet to a particular story or performance. In this way, the carpet becomes more integrated with traditional classroom activities – designing and painting the carpet are part of creating the story or performance. Thus, the modular design of the carpet reflects the need to deploy it in real classrooms where it has to be stored, rapidly deployed, resized and integrated with traditional activities.

Gesture recognition for vertical movement

The children had stated that they wanted to control the up and down movement when on the magic carpet — a challenging design task as research has shown that children and adults have more difficulty spatially locating objects and places in the vertical plane [21]. Brainstorming generated ideas and to demonstrate these ideas to other class members. Ideas for moving upwards included pointing up, jumping and making a climbing action (as if climbing up a ladder). Ideas generated for downward motion included crawling, holding an object down and bouncing a ball. We decided to use video tracking to capture the children's gestures while using the carpet.

There is a large and expanding body of work in computer vision on the identification, tracking and characterization of human body movement [9]. Proposed approaches typically use motion cues to identify objects of interest and rely on often quite complex models of the motions expected. The focus of video tracking work in KidStory has been on the requirements imposed by deployment in real classroom environments. Two types of gesture-based navigation were tested with groups of children in the school; one relied purely on body movements and the other included the use of props. For the first, the children jumped up and down to make the picture on the display screen move up and crawled to make the picture move down. Although enjoyable, one problem was that when crawling the children would lift their heads to be able to see their position within the story space, therefore stopping the action. The second required props for navigating up and down, pieces of card with red on one side and green on the other. By holding up the card with the green side facing forwards they would move up, by holding the card with the red side facing forwards they would move down. The children were also told that they had to place the objects on their head (to get them at a similar height). Some children found it difficult to remember which color moved in which direction.

Initially the props used were plain shapes. However, the class discussed the use of different shapes (see figure 6 for an example), such as an umbrella, kite or a balloon for movement upwards. It proved more difficult to think of objects for moving downwards; some examples included a spade, a parachute and a fish. The teacher and researchers also explained to the class that it may be difficult to use a shape such as an arrow or a pointing finger as they may be picked up upside down.

Figure 6: video-tracked props used to control vertical movement when enacting a story (see color plate on page 557)

Figure 7: Navigation using barcoded pictures (foreground) and barcode reader (background) (see color plate on page 557)

Barcodes for direct navigation

In earlier school sessions children had requested the ability to select a story element from within KidPad by showing the computer a picture of this element. Pictures of story objects, previously drawn by the children, were assigned bar-codes and scanned in order to upload them onto the screen (see figure 7). The system was then set up so that if an object had already been uploaded then scanning that object again would

move the user directly towards the given object, similar to following zooming-links with the hand tool in the conventional KidPad interface. Barcode navigation was used during the next school session for zooming to an object or a location that was far away (off screen); then the magic carpet was used for a finer level of positioning (including zooming forwards). Bar-code navigation appeared to complement navigation using the magic carpet and seemed to be especially useful to travel 'home', the starting position from which the entire story could be seen. This was the most frequently used bar-coded picture and from here the children could then navigate the magic carpet to scenes visible on the screen.

When deciding where to travel when using the magic carpet there was usually some form of discussion and group work; however when using the bar-coded objects, one of the group tended to dominate.

Phase 3: Working towards a retelling performance
In the last two school sessions pairs of children used the magic carpet, barcodes and bar-coded and video tracked props in combination to re-tell a story using KidPad. Children gave the rest of the class, who acted as the audience, a guided tour of the island where the story was set, narrating the different places and objects visited (see figure 8). The barcode tended to be a faster method of navigating to a specific point, once this point had been reached; the children would then use the magic carpet to make fine movements around and into the object they had reached. The teacher commented that this may be especially well suited for re-telling a story to keep an audience involved, and that this method of 'jumping' around the screen seemed to be more obvious and easier to use than the process of setting up arrows to join story elements and then traveling through a set sequence of arrows as is used with the traditional KidPad set up.

Figure 8: Children presenting their story to the whole school (see color plate on page 557)

REFLECTIONS AND DESIGN GUIDELINES
Based on our experience with the magic carpet, we propose several guidelines for the design of physical and tangible interfaces for use in classrooms.

1. Physical size and props encourage collaboration
Physical and tangible interfaces have great potential to encourage two aspects of collaboration among children. The first is collaboration in the use of an interface. This kind of collaboration has been the traditional focus of research into collaboration technologies – how do people use computer technology to accomplish a shared task? The second is collaboration between those directly interacting and those observing the interaction, i.e., an audience. This kind of collaboration has been less of a focus with two main exceptions. Ethnographic studies of real-world settings such as control rooms have shown how those interacting with computer technology often subtly make their activities available to others within the local milieu [12] and some recent on-line performances have focused on interactor-audience relationships [3].

The magic carpet facilitates both kinds of collaboration as a group of children work together to tell a story to an audience. We have observed several examples of how an audience can learn by watching. In one storytelling session, a group of novices who had never seen the carpet before watched a performance before trying to use the carpet themselves. They demonstrated a clear understanding of how to set about using the carpet. In the same session, several other children in the audience spontaneously began shouting out instructions. We propose that two aspects of the design of physical and tangible interfaces can support such collaboration.

Physical size
Designing large artifacts encourages collaboration. The large size of the carpet compared to a traditional mouse and keyboard has several effects:

- The pace of interaction is slower, allowing more time for others to observe the interaction, predict the user's intentions, and potentially interrupt or otherwise react.

- Interaction is more legible to audiences, with benefits in terms of theatricality, interest generated and also learning by observing.

- It is physically harder for a single child to work with the large carpet than with a mouse, and coupled with the way that multiple sensors are combined, this encourages collaborative activity.

Physical props
The second aspect is the role of physical props. Having to move to pick up and then wield a prop slows down interaction and makes it more explicit and open to interruption than reliance on tracking bodily gestures. Providing different numbers of props encourages different styles of collaboration. If everyone has a prop, then everyone has a vote. If there is only one prop, then turn taking has to be

negotiated. Interestingly, although making the carpet larger and using external physical props may benefit collaboration, it may also make interaction more difficult for an individual. There is a deeper HCI issue here; a more general design trade-off between optimizing interaction for an individual and requiring additional effort to make their interaction visible to others. A potential benefit of the use of tangible and physical interfaces is that this trade-off can be managed simply by changing the physical size of the artifact or the number and design of supporting props. This is especially easy if the artifact has a suitably modular structure.

2. Different interfaces emphasize different actions

Although slowing down navigation may benefit collaboration, some aspects of navigating with the carpet were unnecessarily frustrating. Approaching and aligning to an object in the story often required many fine movements, overshoots and corrections. Some of these problems might be attributed to the performance of the early prototype implementations – no doubt a smoother system response would have helped. However, there are other aspects to this issue.

The carpet was used to navigate stories that had originally been created in KidPad using a laptop computer or a PC. To create an object in the story, the children would have used the mouse (for panning) and keyboard (for zooming) to move to a location before drawing some content. Consequently, navigating back though the story would favor the use of a mouse and keyboard rather than the carpet, as it would be easy to recreate these same movements. Compared to the mouse and keyboard, the carpet emphasizes different degrees of freedom of movement. Zooming is emphasized on the carpet, but up/down panning is less so, as it requires the use of the video tracked props.

One consequence of a future proliferation of tangible interfaces is that there will be a greater diversity of devices, each crafted for a particular purpose. Designers need to carefully consider the ways in which these subtly emphasize different actions, especially in situations where they are used at different points in a single experience (e.g., content creation versus subsequent content navigation).

3. Superficial changes may produce very different physical interactions

As noted above, the design of the carpet's surface had a significant impact on the children's interaction. When rectangles were used to indicate the position of the sensors, the children tended to jump on them vigorously. When arrow shapes were used, they tended to place one foot cautiously on each arrow. Of course, it is a familiar idea that the appearance of an interface will affect users' expectations as to required actions. However, it seems here that apparently superficial changes to interface design produce quite dramatic differences in the nature of the children's physical interaction. Perhaps this is because tangible and physical interfaces afford a wider variety of physical actions than do traditional interfaces – there are only so many ways that you can move a mouse!

4. Focus on open low-tech technologies rather than (over) polished products

Space is a scare resource in a classroom. Use of technology within real classrooms requires it to be portable and physically adaptable to a variety of spaces of different sizes and shapes. We often had to set-up the carpet from scratch within half an hour and then completely pack it away again after use. In everyday use, teachers would have to work more quickly than this and on their own too. A physically modular and foldable design is required, hence our design of separate blocks of pressure mats that be laid out in different shapes and sizes and covered up.

In agreement with reflections from the StoryRooms project [1], we find that it is important for the children and teachers to design as much of the technology themselves as is possible so that they can adapt it to particular stories and settings. The design of the technology can itself become part of a long-term classroom project, and in return, the children may learn more about how the technology works. It is also important that the new technology integrates well with more traditional classroom materials such as paper, crayons, card, string and glue. Using physical props (e.g., with video tracking and the barcode reader) is useful as children can design these themselves, weaving them into the story. Again, the modular design of the carpet as pressure mats under layers of material allows the children to design the surface of the carpet or even lay out the pads in different ways. Designers of classroom technologies should avoid over designing. A modular, tailorable, paintable technology, however rough it looks, may be more useful than a polished and moulded plastic design that cannot be opened up.

CONCLUSIONS

We have described the evolution of physical and tangible interfaces to KidPad that support group interaction. Our main aims have been to scale up KidPad to support storytelling activities involving large groups of children, including enacting stories to audiences, and to allow KidPad to be better integrated into real classroom environments and practices, and with traditional materials. An intensive iterative design process, working with children and teachers in school gave a final design that integrates a number of technologies into a "magic carpet". These include arrays of pressure mats under the carpet and the use of physical props that are associated with either barcode or video tracking technologies. Our experiences have resulted in four guidelines for the design of tangibles for classrooms:

- *Use physical size and physical props to encourage collaboration* – large artifacts and the use of props can make interaction more visible and open.

- *Watch out for how different interfaces emphasize different actions* – content created using one interface may be difficult to access using another.

- *Be aware that superficial changes can produce very different physical interactions* – whole body interaction can be more varied than use of a mouse or keyboard.

- *Focus on open low-tech technologies rather than (over) polished products* – children and teachers should still be able to make use of traditional materials.

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