# How Many Ways Can You Mix Colour? Young Children's Explorations of Mixed Reality Environments

*Silvia Gabrielli, Eric Harris, Yvonne Rogers, Mike Scaife and Hilary Smith*

School of Cognitive & Computing Sciences
University of Sussex
Falmer, Brighton - BN1 9QH, UK
{silviag, erich, yvonner, mikesc, hilarys} @cogs.susx.ac.uk

**Abstract**

How do we conceptualise and design mixed reality environments (MREs) to support creative play? Here we describe a first pass at a conceptual framework and use it do design a MRE for young children to explore in, focussing on the familiar activity of colour mixing. Different set-ups were provided, where paint or light colours could be mixed, using either physical tools, digital tools or a combination of these. The paper describes how children collaboratively discovered creative ways of using the mixed reality spaces for colour-mixing. We reflect on the success of the framework and our findings for designing effective play in MREs.

## 1. Introduction

Recent advances in the design of interactive technologies have allowed the possibility of designing 'mixed reality environments' (MREs). Drascic & Milgram (1996) offer one description of them: "Between the extremes of real life and Virtual Reality lies the spectrum of *Mixed Reality*, in which views of the real world are combined in some proportion with views of a virtual environment" (pag. 123).

From a theoretical point of view we can consider a potential distinction as being that between: (i) the 'real' world where spaces and artefacts are acted on by conventional physical actions and where the user's understanding is, therefore, in terms of general causal models of the world and (ii) the 'virtual' where a different, and as yet little-understood, set of causal models operate and action is arbitrarily coupled to the properties of the perceived world. However, we now also have the possibility of extending the ontological profusion of worlds and objects to include environments with pervasive computing properties, building artefacts that have embedded digital intelligence. To some extent such objects have properties of both the former two. This raises the question of how people will deal, not only with the virtual spaces that Drascic and Milgram describe, but with MREs that combine real, virtual and ubiquitous forms.

To approach this question requires a mix of theoretical and empirical work and this paper will attempt both of these tasks. Minimally, we need a terminology/taxonomy that allows us to describe acting in and on these forms and we offer a beginning set below. But we also need to link this to appropriate empirical work, to see how far these concepts have utility and whether they can be useful for future design of MREs. Here we describe a MRE for young children, designed to exemplify and investigate the possibilities suggested by our taxonomy.

## 2. Conceptualising mixed reality spaces

We conceptualise a mixed reality space in terms of a basic construct of *transforms*. By this we mean changes in the state of the world. People encounter, and represent, transforms between states of the world routinely in everyday life, for example in perception (e.g. seeing an object disappear and then reappear or changing one's viewpoint), in action (e.g. when the purpose of a gesture changes) and in cognition (as when we re-represent and re-interpret the state of the world). Dealing with transforms will involve some implicit or explicit theory of what causes changes of perceptual/cognitive states, i.e. some sort of causal link is usually involved. Transforms are a constant feature of ongoing perception and cognition. For this reason we propose the additional term *transform type* to identify the different kinds of forms involved, viz the real, virtual and digitally-enhanced trio identified above. For our purposes, however, we will use the term 'physical', rather than 'real', in this paper to allude to actions/activities/effects which do not involve virtual/digitally-enhanced artefacts. For the latter we shall use 'digital' as a cover-all term.

## 3. Designing an MRE: the Chromarium

In order to instantiate these conceptual distinctions we designed an MRE for young children as part of the Equator project (http://www.equator.ac.uk). Our goal is to create a particular form of a mixed reality space that enables children to experiment and play across different media and representations. In particular we wish to demonstrate something of the unique properties of the digital to enhance the physical by offering certain kinds of external cognitive support (Scaife & Rogers, 2001). The chief objective in the design of the present MRE is to get children to both experience and reflect upon their interactions, allowing some hypotheses about their conceptualisations of these environments. At the heart of our design was the need to exemplify a variety of transforms, based on the combinatorial possibilities of real, virtual and ubiquitous forms.

To this end we developed an activity space, called the Chromarium (a space where colour may be contained, observed and experimented on). It was designed to enable children to carry out a *familiar* activity – that of mixing colours – in a variety of familiar and unfamiliar reality modes (see Table 1). The rationale for using familiar/unfamiliar as an organising concept here is that it should reflect experience and, consequently, that unfamiliarity should provoke reflection, by the child, on what is involved in its experience.

| MR mode | Level of familiarity |
|---|---|
| Physical action→ Physical effect (PPt) | Highly familiar kind of experience for children. |
| Physical action→ Digital effect (PDt) | Less familiar kind of experience. |
| Digital action→ Digital effect (DDt) | Not familiar kind of experience for children of this age. |
| Digital action→ Physical effect (DPt) | Highly unfamiliar type of experience. |

**Table 1: Type of mixed reality experience and children's existing level of familiarity with them**

The core activity was centred around discovering and experimenting with mixing colours. The specific subsets of this which were instantiated in the design were:

- which secondary colours are obtained from mixing two primary ones (e.g. red and yellow)?
- what happens when you mix two secondary colours together (e.g. green and purple)?
- what happens when you mix all the primary colours together (i.e. red, yellow and blue)?

The Chromarium was also designed to enable the children to experience the different effects that occur when mixing colours using different media, i.e. using paint or light. Mixing lights causes different effects to mixing paints (for example, mixing all three additive primary colours using lights produces white, whereas mixing the primary paint colours (subtractive primaries) produces a brown-black colour).

Thus, in all cases the identity of the transform remains constant: colour mixing (although the particular form of this will obviously vary). What we do here, however, is to alter the transform type, in the sense described previously. Four types were set up, labelled according to the mechanisms involved. It is important to realise that we are referring to the *mechanism* which potentiates the transform. Thus a 'digital action' (like using a painting program on a display screen), inevitably involves some degree of physical action on the part of the user, but it is the (digital) mechanism that allows this that is crucial here.

**Physical to physical transform (PPt: action and effect of same kind)**

Here we set up two forms of PPt. The first involved mixing paints, the second mixing lights. Mixing colours with paints is a straightforward physical activity: using a paintbrush, wet paints are selected from different pots and combined on a palette. It is easy to add colours but not to remove them. To mix colours with lights, torches with different coloured filters are shined underneath a perspex surface (Fig. 1). With light, it is also easy to add and remove colours when mixing them.

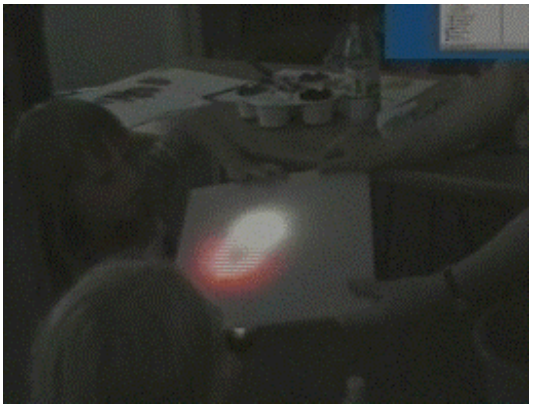

**Fig. 1: Children mixing-colours using torches**

**Physical to digital transform (PDt: action in physical with digitally-based effect)**

Here we used RF technology to enable physical actions to trigger a virtual effect. Two coloured blocks, having a different colour displayed on each face were built, each face being embedded

with an RF tag. When a face was read by the tag reader (Tag-it), an animation (written in Macromedia Director) mirroring the colours would appear projected onto a wall. The tag reader was concealed beneath a table surface. Children were asked to mix colours selecting one side of each block. The effect would likewise appear as a digital animation, showing which colours had been selected and what colour they mixed into.

The Director movie displayed a digital representation of the coloured blocks that were placed in the physical space, depending on which colour was face up on each physical block. The movie's script set the tag reader (connected via the serial port of a PC) to continuously read tags within its range using a specially written serial Xtra. Each tag read was then translated into a displayed image of the block. When two blocks (tags) were read a short animation showed the effect of mixing the two selected colours and was accompanied by a variety of sounds (Fig. 2).

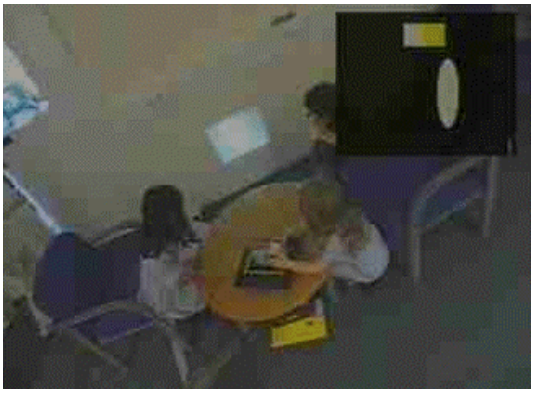

**Fig. 2: Children playing with blocks to explore a PDt**

**Digital to digital transform (DDt: action and effect of same kind)**

Here we used interactive screen technology to enable digitally-potentiated actions to trigger a virtual effect. Two software tools were provided (Mixing Colours and Computer Crayons) that enabled colours to be selected and mixed in a digital space. Both involved dragging coloured discs (representing paint or light) to overlap. An interactive horizontal surface was provided using a back projection onto a table surface and mimio™ input devices, disguised as a paintbrush or a torch, were used for selecting the colours. The "paintbrush" activated the discs to move when the brush hairs were pressed against the discs on the table surface (Fig. 3). The "torch" was held slightly away from the surface and a button on its side was pressed to activate it. In this space it is easy to add colours and subtract them once mixed in both the light and paint tools.

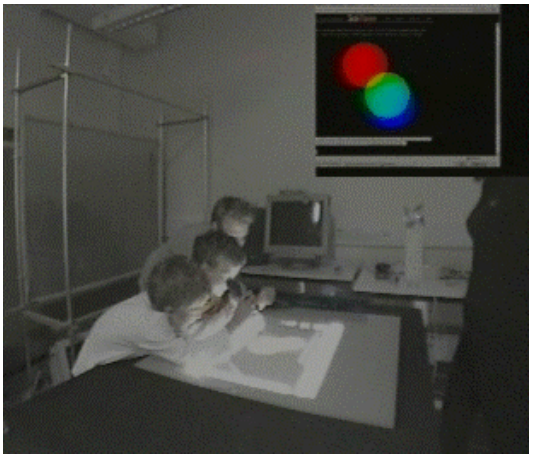

**Fig. 3: Children experimenting with colour mixing in DDt**

**Digital to physical transform (DPt: digital action with physical effect)**

Here we used interactive screen technology to enable digitally-potentiated actions to trigger a physical effect.

An animation of a two-coloured windmill was displayed on the same horizontal interactive surface. Clicking on the image of a cloud or the windmill in the animation triggered both the effect of spinning the digital windmill and, at the same time, the spinning of a physical windmill placed nearby (mirroring effect, see Fig. 4).

The windmill animation was written in Director and again used the serial port of a PC and a serial Xtra to interface between the movie and a children's toy windmill. The physical windmill was controlled via an input / output circuit board (from EZI/O™) to switch on a small motor. When the motor was switched on by the movie it turned the windmill for approximately five seconds.

## 4. Method

Five pairs of children, aged between 5 and 6, were asked to take part in the Chromarium study. They were told that they would be mixing colours in fun and unusual ways. The children were allowed to explore the various activities as they liked.

To get some data on their understanding, we prompted them to talk about their experience in the different set-ups, by asking open-ended questions such as: 'what do you think will happen if…?' or 'How do you think this is working…?'. To elicit further explanations from the children we also made use of counterfactual questions, such as asking the children to say

what would happen if they tried to mix other materials (e.g. paper, fabric) compared to the effects produced by mixing paint or light. The children were video recorded during the activities.

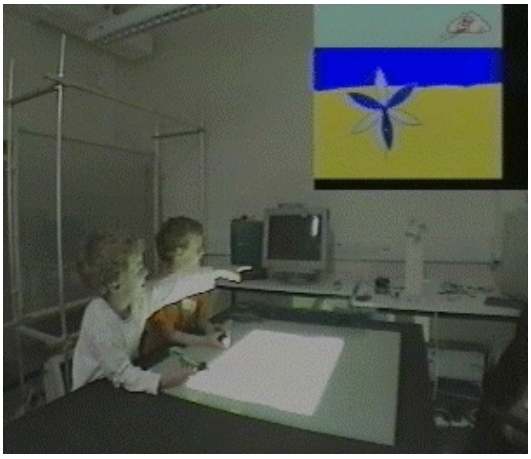

**Fig. 4: Children mixing colours to explore a DPt**

## 5. Initial findings

In this section we discuss some of our initial findings. Two key questions we ask of the data are:

- Were children creative in interacting with the differing activities?
- Whether their behaviour and comments showed evidence of discrimination related to the different colour transforms and mechanisms enabling them.

Our findings showed that children were able to collaboratively discover creative ways of using the mixed reality set-ups, while appropriating the activity of colour-mixing. We observed they were particularly creative when they could freely explore and manipulate the materials provided. It was when dealing with mobile objects, like torches and blocks, that they were more active in experimenting different mixing effects or in inventing other potential uses of the same artefacts. With torches children liked to play at moving them away from the perspex surface so as to obtain larger shining effects and better mixing. When using blocks we noticed that children were trying to discover if the tag-reader surface was able to identify or capture other objects rather than just colours. Two girls for example, touched the tag reader area with their faces, expecting to see them scanned and projected on the wall, something that would have added interest to their playing and interaction with the digital world. Children also liked to mix colours by using real paintbrushes or the mimio™ ones.

Other interesting observations emerged from children's manipulation of the blocks in PDt. The children began by placing the blocks in towers to see whether anything would happen (we had not designed for this combination). They also expected digital events to happen when moving the blocks together away from the table surface. Sometimes they pressed the blocks down hard on the table surface, as if trying to amplify or speed up the feedback from the animation. Some of the children needed to enact different explorative behaviours before discovering which one of the block's faces was read and how. They tried to put the blocks against the computer screen that was behind them or against the image projected on the wall to see if any effect was coming out. They also tried to see if they could select a block's face by orienting it towards the area projected on the wall.

In DPt we observed that sometimes the children focused on the digital effect caused by the digital action and failed to notice the physical effect (physical windmill spinning). This could be due to the children's initial unfamiliarity of relating their action in the digital space to the type of feedback coming from the physical world.

The children seemed to enjoy all of the different set-ups, especially the experience of PPt and PDt. This was probably due to the larger degree of freedom afforded by the activities they could perform and to the richness of the feedback they could get from their actions, for example the combination of sounds and animations associated with their manipulation of the physical blocks. The children also said they enjoyed mixing colours in DDt, while they expressed the desire of being able to try more different types of transforms within the DPt. They provided many suggestions on how to improve it to make it more fun.

The activities children performed in PPt were found most useful to enable them to elicit the knowledge they might already have acquired in nursery or school settings about the domain of colour-mixing and its main properties (differences between mixing paint and mixing light). However, it was apparent that not all children were familiar with the idea and rules of mixing coloured lights, whereas, as expected, they were all familiar with paint mixing. The evocative function of this condition can be exemplified by the following quote from one of the children. To the question 'Did you know you can mix colours like that with torch light?' he replied 'No, but I do know what you can do with sun and rain. I know how you make a rainbow. Sun reflects on rain'. When we used counterfactual prompts, such as, "Is paint like mixing yellow and red material?" we got

answers of the type, "…no, because it's not runny!".

We found that activities in DDt helped the children to develop a more complex knowledge of colour-mixing, since it seemed that they were transferring their experience of the PPts to the digital space, where more complex reversals were possible (like taking a colour away of two).

Activities performed in PDt and DPt turned out to be the most interesting for children to provide causal explanations about the mechanism enabling the transforms. Their understanding of the causality involved in these transforms seemed to be affected by their actions producing effects 'at a distance' in a different space. This was especially the case when a small delay intervened between their action and the effect in the physical or digital world. When we asked the children to explain where the effect of the animations, triggered by the physical manipulation of the blocks, came from, they said things like: "the effect is coming from the computer's screen over there, and it arrives here by means of electricity" (6 year-old girl). Another child (a 5.8 year-old boy) pointing first at the table under which the tag-reader was concealed, then to the projected image, then to the computer said "…connect, connect, connect…wire…it is connected under here [*table*] and goes all the way up to there!" [*PC behind him*].

Children seemed to understand there were causal links between distant objects and their actions, but their explanations were often an idiosyncratic mix of magical thought with bits of previous knowledge. For the DPt, some children did not understand that they could control in the virtual space the effect obtained in the physical world. A 6 year-old girl, for example, said that the spinning of the physical windmill was caused by the wind coming in from a window (even though no open window was available in the laboratory to justify her answer). However, two boys, on a different occasion, were quite clever at understanding causality for this effect. By looking at the windmill in the physical space they said '…this [*digital windmill*] is making that go round and round, because we are using this [*the mimio pen and the digital windmill*] …and they are connected with wires!'. They were also very explorative towards the surrounding environment when we asked them to give explanations about causality and mechanisms supporting the transforms between physical and digital space. They looked under the table to discover which device was causing an effect and how the different apparatus were connected to each other.

## 6. Discussion

Our findings extend the corpus of recent research on providing digitally-based play activities for young children. These have emphasised the value of open-ended forms of play for facilitating the acquisition of complex forms of thinking and acting (e.g. Cassell et al., 1999; Kolomyjec at al., 1997). During this kind of play children typically create an explicit imaginary world or situation with implicit rules. In addition other research has also begun to capitalise on the value of manipulative materials and objects to make more concrete and tangible children's playing and learning activities (e.g. Colella et al., 1998, Resnick et al., 1998). The observations made in the present study support the idea that open forms of play can be well-supported by digitally augmented objects which children are free to manipulate in a three dimensional space, as representational or pragmatic devices. Of particular relevance in the present context, is how children's creativity appears to be enhanced when their physical activity in the playing world is matched to produce rich multimedia effects in a digital space.

A main finding was that children found it intriguing to experiment with colour transforms in the different set-ups provided and to reason about the mechanisms enabling the MR transforms to happen. Our initial findings indicate that children had a good causal understanding of the way the transforms worked in the Chromarium. It seems that the richer and quicker the feedback provided (such as the digital to digital), the easier it is for children to understand the causality involved in the MR transform. Future research aims to investigate how counterintuitive and more complex forms of feedback can be designed to see if this facilitates richer causal abilities and, consequently, more elaborate forms of creativity during children's play in MREs.

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