KEY TO THEMES OVERLEAF

From research to design: Perspectives on early years and digital technologies

futurelab
innovation in education

Key to themes

Futurelab understands that you may have specific areas of interest and so, in order to help you to determine the relevance of each project or publication to you, we have developed a series of themes (illustrated by icons). These themes are not intended to cover every aspect of innovation and education and, as such, you should not base your decision on whether or not to read this publication on the themes alone. The themes that relate to this publication appear on the front cover, overleaf, but a key to all of the current themes that we are using can be found below:

Digital Inclusion – How the design and use of digital technologies can promote educational equality

Teachers and Innovations – Innovative practices and resources that enhance learning and teaching

Learning Spaces – Creating transformed physical and virtual environments

Mobile Learning – Learning on the move, with or without handheld technology

Learner Voice – Listening and acting upon the voices of learners

Games and Learning – Using games for learning, with or without gaming technology

Learning in Families – Children, parents and the extended family learning with and from one another

Informal Learning – Learning that occurs when, how and where the learner chooses, supported by digital technologies

For more information on our themes please go to **www.futurelab.org.uk/themes**

This publication is available to download from the Futurelab website – **www.futurelab.org.uk/openingeducation**.

Also from Futurelab:

Literature Reviews and Research Reports
Written by leading academics, these publications provide comprehensive surveys of research and practice in a range of different fields.

Handbooks
Drawing on Futurelab's in-house R&D programme as well as projects from around the world, these handbooks offer practical advice and guidance to support the design and development of new approaches to education.

Opening Education Series
Focusing on emergent ideas in education and technology, this series of publications opens up new areas for debate and discussion.

Contents

Publication 1 from the Futurelab PhD Studentship Network
August 2008

Sarah Eagle
Andrew Manches
Claire O'Malley
Lydia Plowman
Rosamund Sutherland

Foreword

This publication is a first for us as it brings together early work from Futurelab's PhD studentship network. This network was set up to bring together PhD students and their supervisors from Bristol, Nottingham and Stirling universities to explore how these different groups might, collaboratively, explore challenging questions around the role of digital technologies in young children's learning.

The three papers in this publication represent our progress in this ongoing conversation – they present the early arguments developing within the two PhD projects, but also the wider issues that these projects are raising for the design of digital technologies for this often-overlooked age group. More than this, however, the papers in this publication explore how we can use existing research traditions to create challenging new directions for design and development in this field.

In publishing these papers, we begin the process of opening out this conversation – we're looking forward to hearing what you have to say about these ideas.

Keri Facer
Research Director

Paper 1: How might research on family reading practices inform the design of interactive digital resources for pre-school children?

Sarah Eagle, Graduate School of Education, University of Bristol

Introduction

This paper is a think-piece based on the observation that both books and interactive digital technologies are objects which feature in the homes of many young children and are often thought of as having a particular role to play in preparing children for learning at school. It explores the potential links between research into children's learning with books and the design of interactive digital technologies for use by young children in the home.

Children's earliest learning takes place through their experience of everyday life at home, a space in which even very young children are increasingly encountering digital technologies. To date, however, we know little about how these tools might support learning for very young children in the home.

In contrast, children's books have been with us for generations and early reading and literacy practices have been subject to significant research attention. For hundreds of years, printed language has been the form in which knowledge and ideas have been stored and distributed, so it is a given in today's society both that reading and writing are essential for learning and that books and literacy materials are an important part of schooling. The importance of literacy in schooling and society as a whole underpins academic research into how children learn to read, research which includes studies of everyday practices in children's homes with books and other printed material.

Our suggestion in this piece, then, is that we might usefully draw on this longstanding research field examining how children learn with books and printed materials in the home to inform our thinking about how we might design digital technologies for young children's learning in the home.

This suggestion may meet with some surprise – how can we think of books and digital technologies in the same way? And yet, when we look at developments in the interface and design of digital technologies over the last three decades, it becomes clear that where computers were once simply programmable devices, they are now tools that we can easily use for all kinds of work and leisure activities: as well as for programming and mathematical tasks we use them for writing, designing, communicating, playing games and accessing information, and more. Ongoing developments with technologies frees us to use a working assumption that there is unlimited potential of form and purpose for which digital technologies can be used.

At the same time, although the possibilities for interactive digital technologies may seem to be endless, experience has shown that new inventions and ways of using come not so much 'out of the blue' but emerge from an existing context. People always approach using new tools and technologies in the context of existing practices with older technologies. The way we use interactive digital technologies – to write and design, access information, communicate and play – builds on what we were already doing with pens and paper, libraries and encyclopaedias, telephones and games. Where we understand our existing practices well, we have a useful basis for thinking about what kind of new technologies we might develop and the ways in which they might change and potentially improve on what we were doing beforehand.

As such, it is not hard to believe that there may be lessons from studies of family reading practices for designers and researchers of young children's use of digital technology in the home for learning.

A note on terminology

It should be pointed out that, whereas much of the research reviewed focuses on mothers reading with their children, for many families those who read with children in domestic settings may in fact be fathers, siblings, extended family members or childminders. In addition to this the notion of **family** is not straightforward, many children's experience of domestic life taking place in more than one setting. While recognising this diversity, this paper uses the terms **parent**, **family** and **home** for the sake of simplicity.

Everyday family practice: the perspective of this paper

Designers of interactive digital technologies for learning may already be familiar with research that cognitive psychologists have carried out which contributes to our understanding of how children learn to read. This research includes, for example, work which develops an understanding of the processes by which we learn how words are made up of smaller sounds (phonemes), and processes involved in learning to recognise letters and letter sequences[1].

This paper, however, is concerned with understanding how **everyday practices** at home contribute to children's literacy development. It draws on a perspective termed New Literacy Studies which arises from anthropological and ethnographic studies of literacy practices in different cultures[2,3,4]. This research seeks to understand literacy in terms of the situations in which, and the purposes for which, people employ their reading and writing skills, namely, the everyday practices that are meaningful in people's lives.

Because young children first learn about the world through their experience of everyday life at home, their earliest learning about reading and writing will be through the literacy practices that are meaningful within their homes. The anthropologist Barbara Rogoff describes young children's learning within families and communities as "guided participation", "the process and system of involvement of individuals with others, as they communicate and engage in shared activities"[5].

Her research demonstrates how children learn through observing, involving themselves in, and imitating what people around them are doing. In her studies, she observes that children do not always leave it to adults to arrange for them to take part in activities, they find ways of negotiating their own practical involvement and they include make-believe versions of adult activities in their play[6]. Children, likewise, engage in early reading and writing behaviours through which they develop an understanding of reading and writing on which their own skills are subsequently built. These early behaviours are called **'emergent literacy'**[7].

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

Emergent literacy can be thought of as arising through children's involvement in three roles: as observers of other people reading and writing in the course of everyday life; as **imitators**, incorporating pretend reading and writing into their play; and as **participants** in reading and writing activities.[8]

Picturebooks and storybooks for children can be seen as objects which are tailored for children's participation in two of these roles. As imitators, children can use books, along with pens, paper and other literacy materials as part of their pretend play; and as participants, when sharing books with others children have a close up view of what people are actually doing when they are reading.

Sharing books

For generations, families have been reading stories to young children. This has been encouraged as a practice which contributes to preparing children for school. In 1975 a report by the Bullock Committee, set up to examine language across the curriculum, stated:

> "...the best way to prepare the very young child for reading is to hold him (sic) on our lap and read aloud to him stories he likes, over and over again... We believe that a priority need is... to help parents recognise the value of sharing the experience of books with their children."[9]

This recommendation makes a connection between books, stories and literacy, and alludes to values about books and printed material in the educational world. There was, however, an important gap in this recommendation, as Margaret Meek pointed out in her book 'On Being Literate':

> "Reading to children before they go to school is now widely, and, I think, wisely recommended. But, straightforward as it seems, the practice is by no means self-explanatory... What, then, is the relation of being literate to being read to, and why?"[10]

Through the 1980s, research evidence began to address this question and started to detail the relationship between children's experience of literacy practices (such as being read to)

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

and their subsequent attainment in school[11]. Research has shown that what is important is more than just hearing stories read; what facilitates learning is the interaction between parents and children as they share books.

Studies of shared reading date back to the late 1970s, when Anat Ninio and Jerome Bruner published a study of one mother and her 10 month-old son using books together[12]. They described joint book reading as a shared process of meaning-making in which both parent and child were involved in pointing at pictures, naming elements of pictures, turning pages, and during which the parent encouraged and praised the child.

Ninio and Bruner's study opened up a field of interest in shared reading on both sides of the Atlantic, using larger samples over longer time periods and concerned with practices of people from different cultures, social classes and educational backgrounds. Shared reading has been studied by researchers from psychological, sociological and anthropological backgrounds using methods which vary from large-scale surveys and long-term ethnographic studies, to detailed case studies[13,14,15,16,17,18].

These studies have shown that children are active participants in the physical sharing of the book, in asking questions and suggesting answers, and that adults help to negotiate meaning by making stories relevant to the child's life, explaining, monitoring the child's understanding, and giving praise and feedback. During storybook reading, an adult who knows the child well is able to pick up on the connections that the child is making, make sense of them, and to expand on what the child has contributed, answering questions and joining the child in exploring the meanings and ideas that they discover.

It has been pointed out that these patterns of adult-child storybook sharing are typical of what one researcher described as 'mainstream' families whose practices are closely allied to practices in schools. There are potential differences between this way of using books with children and those of families from different social and cultural backgrounds. Comparative studies show how these differences are drawn along the lines of personal experience and cultural beliefs about learning and education. A ten-year study of literacy practices amongst three diverse communities in the US19 and another carried out in the Netherlands[19] showed how, in some communities, reading with children involves encouraging them to repeat words or phrases, and discouraging rather than encouraging them to relate elements of the stories they read to their own lives. Other research has shown differences in parent/child book sharing **within** communities, comparing the practices of parents of different educational backgrounds[20,21].

Do these differences impact on children's progress at school? Research suggests that they do: where practices in schools build on practices that children are familiar with at home, children's progress is facilitated. Where the literacy practices of home and school are dissimilar, the reverse can happen.

Drawing on this research, family literacy programmes[22,23,24] have developed methods for helping families to involve children in literacy practices in ways that are designed to help prepare them for those of school. Typically families are encouraged to support their child's developing literacy skills by providing children with books and other literacy materials, recognising and encouraging what they do, modelling reading and writing during the course of everyday life, and interacting with the child in literacy activities, for example when reading storybooks together.

Time and place

In many families there is a particular niche for shared storybook reading; it is a regular activity that takes place at bedtime. Susan Nichols[25] observes that parenting magazines and other literature for parents contribute to an idea of bedtime story reading as a long-established practice which those who are concerned with their child's educational progress will naturally adopt.

Nichols argues that from the parent's point of view, time spent reading together at bedtime is justified by additional factors which relate to the economy of time in the household. In other words, reading together is not only seen as a valuable activity in itself, but it serves as a means of getting children settled before sleep, and an opportunity for close personal contact between parent and child, particularly for parents who aren't able to spend time with their children during the daytime.

These factors serve to establish and ritualise the practice of sharing books at bedtime. Although parents may not be fully aware of it, setting aside a time like this has another consequence for children's language and literacy development. Studies of everyday talk in the home suggest that much of daily talk between parents and young children is concerned with the here and now; during busy times of the day families are unlikely to respond to children's questions with explanations and to get involved in extended conversations. During more relaxed, child-centred occasions, when parents are not distracted by the need to fulfil tasks, they are more likely to respond to children's questions and conjectures and to get involved in conversation about experiences and ideas **beyond** the here and now. The subject matter of this kind of talk may be valuable in itself, but over and above that it familiarises children with the kind of language used in books and in schooling[26,27].

The design and use of storybooks

A look at contemporary illustrated storybooks for pre-school children suggests the accumulation, amongst authors and the producers of books, of a depth of understanding about how they are used and read in the home.

A key attribute of a 'book' as a material artefact – alluded to in research, but rarely highlighted – is the way it lends itself to shared use. The shared activity of page turning is one example. Contemporary books are easy to handle, both for children and adults, and can be used in almost any physical situation, as easy to share at bedtime as at other times and places.

The physicality of pages and page turning is also an aspect which has been explored by book designers and producers. Some books for very young children include flaps to lift and look under, holes to look through, three dimensional 'pop-ups' (for example Eric Hill's 'Where's

Spot?'), textures (as in the Dorling Kindersley 'Touch and Feel' boardbooks) and more. All are elements which encourage engagement with the book as an artefact in itself.

Many writers of contemporary picturebooks set out to involve and amuse both adult and child readers, and are aware that conversations arise from their work[28]. Examples are Jill Murphy's 'Five Minutes Peace'[29], 'All In One Piece'[30] and 'A Piece of Cake'[31], a set of stories about a family of elephants which appeal to children while at the same time providing humorous comments on aspects of family life which are aimed at adults.

There are many examples of picturebooks which, rather than telling a story in a straightforward manner, give children opportunities to participate in constructing their meaning[32]. Authors have come up with many ways of doing this, for example by leaving gaps in stories for readers to fill in from their own imagination, using pictures to elaborate and even to contradict elements of the story that is told through the text[33]; and by playing with the everyday and familiar, such as a bear in a story picking up a pencil to draw himself out of trouble[34]. There are examples of books which set out to engage readers by playing games with traditional form and content, reversing, recasting or extending fairytales; making deliberate 'mistakes' that result in disruptions or unexpected events or happenings, or writing a 'fairytale salad', a game that involves mixing characters and adventures from various stories'[35].

Meanwhile, Professors Eliza Dresang and Kate McClelland suggest that a "radical change" has been taking place in children's literature over the last decade[36]. They argue that books for children of all ages increasingly feature characteristics which reflect the interactivity and connectivity of the digital world. Writers and designers make use of cuts, flashbacks, split-screen images, hyperlinks and non-linear progression, multiple conclusions and uncertain endings. Images have an increasingly central role, integrated with the narrative rather than complementing it so that the text cannot be understood without engaging with the images.

Studies of young children reading and interpreting picturebooks make it clear that they are capable of reading seemingly complex texts, appreciating and enjoying play with conventions, genre, form and structure. The research shows us that young children are capable of participating in literacy practices at a level of sophistication which we might otherwise assume **follows** learning how to read in a conventional sense.

The research also emphasises the importance of having a competent co-reader, and argues that sharing books with an adult can help children to develop the beginnings of 'critical literacies' and an understanding of how texts represent particular points of view, and that texts have the power to construct our ideas of the world, and how we see ourselves in relation to it[37]:

> "Teachers, parents and other co-readers who appreciate the interactive complexity of children's books and can enjoy with children both the story and the visual and verbal means by which it is constructed, not only encourage pleasure in reading, but also enhance... children's analytic satisfaction of understanding the ways in which the text is producing pleasure and how it is positioning them as interpretive agents."[38]

Being able to take a critical role as a reader, it has been argued, is one of the capacities that readers need in order to be fully literate in the information-rich 21st century.

A summary of the research findings

Children develop an understanding of literacy through observation of the role of print in daily life, from their own involvement in handling printed texts including storybooks and picturebooks, and in their own playful activities with make-believe reading and writing.

The research reviewed here highlights the important role of social interaction during shared use of books, and the insights can be summarised as follows:

- Young children's experiences with books at home can help prepare them for literacy practices they will later encounter in schools.
- Through their design, storybooks can encourage young children to develop an awareness of the constructed nature of texts, for example through play with form, structure and genre.
- Young children typically participate in story reading as active partners, engaging with others in making meaning of the text.
- Sharing books can be a context in which children and adults talk about ideas and concepts beyond the 'here and now'.

These insights are used to frame four questions to guide thinking about the implications of this research for the design and use of digital technologies for young children in the home:

- How might we think about young children's experiences at home in terms of preparing them for practices with interactive digital technologies in schools?
- How could we help children to develop an awareness of the constructed nature of digital texts?
- How might interactive digital technologies be designed to encourage shared use between young children and others?
- How might sharing interactive digital technologies be a context in which children and adults talk about ideas and concepts aside from the here and now?

Implications for design of digital technologies

How might we support young children's experiences at home with digital technologies in terms of preparing them for use of interactive digital technologies in schools?

It is now widely recognised that literacy learning begins long before children start school39. Within western cultures it is becoming part of child-rearing orthodoxy that families prepare young children for later schooling through various means, including providing them with resources specially designed for their use, including illustrated books.

Parents can obtain advice on how best to read books with children through magazines, websites, public libraries and through family literacy programmes. With or without this kind of guidance, parents' practices with children are likely also to be informed by their own childhood experiences, and by ideas about learning from their own schooling.

While book use with children is valued as educational, and practices in the home are often modelled on practices in schools, the relationship between digital technologies and schooling is much less well established.

In contrast to an established understanding of the educational value of print literacy, there is as yet no generally accepted description of the technical or conceptual skills and knowledge children should develop with digital technologies, either within school or at home.

In the absence of widely accepted ideas about what children should be learning, there is currently no expectation or orthodoxy about what families might do to prepare pre-school children for using digital technologies at school. Nor, given the differences between the digital technologies first introduced in schools 20 years ago and those of today, is there anything in parents' own schooling that they might draw on as a model for introducing young children to the digital technologies of today.

Whereas designers of books are able to use a set of assumptions about how, why, when and where their books will be used, designers of technology are operating in a context that is uncertain and changing, and face the challenge of anticipating what new practices there might be and how they will be established.

In response to these challenges of understanding 'dominant' digital technology practices, one approach has been to look to young people and children as agents of change, as themselves responsible for and capable of defining the dominant practices of digital technology use today. We are seeing educators and policy makers look to young people's use of emerging technologies in the home to begin to attempt to understand what schools might need to teach.

In designing digital technologies for use in preparing young people to enter dominant codes of practice, then, it is likely that we may need to pay more attention to the emerging digital youth cultures or to the ways in which ICTs are used in workplaces. These sites are more likely to provide a representation of future technology practices than the policy guidance on school practices, which many see as increasingly playing 'catch-up' with the outside world.

How could we help children to develop an awareness of the constructed nature of digital texts?

Digital technologies have allowed new possibilities for production that have changed the way we present texts, enabling meaning in **multimodal** texts to be delivered through image, sound, text and layout.

Before we consider how we might help children to build an awareness of how meaning is constructed in multimodal digital texts, it should be emphasised that even before they come to use books, young children are already practised at making meaning across modes. When adults interact with young children they use a combination of language, gesture, touch, gaze and physical action[40]. When children are read stories, adults use all these means of communication in combination with the image and text in the book, giving children multiple resources to draw from in constructing their own meaning of the text. Learning to read print could be characterised as gradually moving from interpreting meaning from the print in combination with other clues and prompts, to being able to derive meaning from the print alone. This perspective implies that young children are multimodal readers before they are literate in a traditional sense.

One research study of young children using illustrated books suggests that picturebooks themselves offer an entry into the world of multimodal texts. They allow "room for the reader's attention to move between words and pictures in a different way each time, so that the reader constructs fluid and plural possibilities out of what seems at first glance to be a singular text"[41]. Picturebooks "open doors for readers to make connections with many different kinds of texts in their own lives... on television with words and images, in audio form with words and music, on computers in multiple incarnations."

We saw earlier that a significant change is happening to children's books which are increasingly designed to reflect the interactivity and connectivity of the digital world. We may suspect that children are developing fluencies in reading multimodal texts, whether on the page or the screen, learning the language of cuts, flashbacks, split-screen images, hyperlinks and so on.

We have also seen that that some authors of children's books have found ways of directing readers' attention to the ways that texts are constructed, introducing the idea that behind texts there are authors who make deliberate decisions about the way they produce meaning, one way in which young children can gain an early introduction to **critical literacy**.

Digital technologies have opened up new opportunities to children to learn about how texts are constructed. Whereas in the past, producing printed texts, animations and films required specialist technology and skills, new digital technologies have made it possible for people to produce all kinds of texts from their own homes. Using new technologies it should be possible to encourage children to acquire their own experience of being producers of texts, becoming involved in choosing how to assemble resources to generate meanings.

In future, the design of digital texts might appropriate some of these features of print texts, by adopting a spirit of self-reflection and directing readers' attention to the way texts are constructed; for example through incorporating parody and disruption and embedding unusual elements for readers to discover, provoking young readers to ponder the structures, forms and devices through which texts are constructed.

The development of software-authoring tools for young children's use is likely also to be

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

a useful development in this field, allowing young children to play and experiment with producing texts, introducing them to the ways in which images and texts are assembled and edited – including cuts, flashbacks, split-screen images and other means.

How might interactive digital technologies be designed to encourage shared use between young children and others?

Earlier in this paper, we saw that during shared reading of picturebooks, adults do more than just read the text. They label and name, praise and encourage, and they also expand on things the child has said, providing more information and answering questions. Children's questions and actions demonstrate that they approach shared reading in a playful and exploratory way, and that they are active in making connections between aspects of the text and their own lives and background knowledge[42]. During shared reading, if parents join in with the child's exploration and with the building of connections between the text and the world as they know it, they are able to contribute to their child's understanding of the text and extend their pleasure in the reading experience[43].

We do not know whether adults share children's use of interactive digital technologies at home, nor whether they do so in playful ways, but we may guess that at present, few technological products for young children explicitly encourage this kind of use in the way that storybooks currently do.

Indeed, when we observe the sorts of digital products marketed to parents and children as educational, we find an absence of encouragement of this sort of playful and shared interaction. While the market is full of books, magazines and products such as CD-Roms and digital toys and games that are explicitly sold as being educational[44] and enhancing children's learning, many of these interactive digital toys promote a form of interaction which contrasts with the playful and exploratory approach that we have seen helps children develop their emergent literacy skills. Instead, they promote a process of explicit, directed instruction and accumulation of factual knowledge by the child which reflects a dominant and popular conception of learning as a process of instruction and knowledge acquisition.

Erik Strommen, a psychologist and designer of interactive toys, argues that such 'instructional designs' (which follow a model of a teacher giving children challenges, encouragement and praise) are easier to market to parents than designs which promote play. As a consequence, he suggests, many electronic toys for pre-school children are based on this idea about learning simply because it makes them easier to sell , despite the research evidence that children under the age of 5 learn through playfulness, exploration, talk and interaction with others[45]:

> "Play is critical to mental growth and development. We have decades of studies from dozens of cultures demonstrating its value for children's social and cognitive growth. We have good data on the processes by which play fosters learning. If we combine this knowledge with technology, enabling play in both virtual and physical worlds, the opportunities to foster playful learning would seem infinite."[46]

These sorts of playful learning are taken for granted in many family reading practices.

Of course, however digital technologies for children are designed, there is nothing to stop parents finding their own ways of sharing their children's use of these toys and resources nor to prevent them to doing so in playful ways. It is, however worth thinking about what might **encourage** parents to be involved in sharing digital technologies with young children such that both parties are active and playful.

For this to happen we would need to see a change in the marketing language and ideas of learning that are used to promote interactive toys and educational materials for the home. The prevalence of instructional designs on the market is likely to contribute to a general notion of what constitutes appropriate early childhood experiences with interactive digital technologies; such an assumption would have to be challenged and replaced by a discourse which highlights the importance of interactions, playfulness and conversation around the object.

Hand in hand with this we would need to see a change in physical design to encourage shared (rather than solo) use. We might want to see designs that support shared use in all kinds of physical situations – such as is allowed by the portability, flexibility and durability of books.

We would also need to think about what kind of designs would be both accessible to young children, interesting to adults, and enjoyable for both. The research literature provides some suggestions. One design principle derives from **Logo**, developed to introduce young children to spatial and mathematical problem solving, but which also offers something of interests to adults because of its **low floor** (easy for beginners to get involved) and **high ceiling** (allowing those who have developed expertise to work on increasingly sophisticated projects). Mitchel Resnick of MIT Media Lab suggests that since modern technologies can inspire and support their users to explore them in all kinds of ways, we should add **wide walls** to this design principle[47].

For our purposes, the **wide walls** principle would mean that an artefact should support both children and adults to explore different ways of using it. Within the research literature there are some suggestions that adults and children alike gain pleasure and enjoyment from this kind of exploration. Some authors design books for children that explicitly encourage readers to explore different ways of reading them; David Macaulay's **Black and White** is a well-known example[48]. We might also think of children and adults reading and re-reading the same book as enjoyment of a predictable theme to which, as they relate it to everyday experience, they bring their own interpretations and variations.

How might other artefacts be designed to support people in exploring different ways of using them and engaging in a shared pleasure of developing variations on a theme? One study, in which young adults explored the interactivity offered by traditional toys[49], described participants as deriving most enjoyment from simple toys which allowed them to explore different ways of using them. By introducing constraints, challenges and goals in the form of rules, ideas and extensions, the participants developed ways of using the toys that ranged from very simple to very complex.

Reminiscent of the way that children use the worlds they know as a resource for working out meanings and filling in gaps in stories, young people used their environment as a resource for extending what they could do with simple toys (for example, elaborating on a simple ball game by introducing a bounce on the table). Toys which offered very specific interactivity were initially interesting but later found to be limited – an observation echoed by parents' comments that children's complicated interactive toys are frequently to be found discarded at the back of the toy cupboard[50].

We might therefore consider developing technologies which are initially simple, but lend themselves to being used over and over again, at the same time capable of allowing adaptation by users and the development of complexity. These designs would aim to engage both adults and children in exploration and adaptation, incorporating ideas from children's lives and the family environment.

How might sharing interactive digital technologies be a context in which children and adults talk about ideas and concepts beyond the here and now?

We saw that, particularly when it takes place at a time when there is no conflicting set of tasks to be achieved, and when adults are able to focus on the activity itself, shared storybook reading can be a particularly rich experience, one in which conversation involves explanations and abstractions.

From this we need to consider how we could design interactive digital technologies to support shared activity that, rather than competing for a specific allocation of parental time, is part and parcel of the activities that families prioritise in everyday life. We need to consider how this activity would foster a relaxed atmosphere in which, rather than being interruptions, children's questions and ideas are appreciated and explored.

Without further research, it is not clear how resources could be designed around families' organisation of time and prioritisation of activities. As suggested earlier, families are likely already to be developing new ways of using digital technologies for everyday practices in ways that involve children. One example might be ways in which families involve younger members in taking, manipulating and sharing digital photographs. Another might be ways in which families involve young children in producing blogs, web pages and e-mail.

The challenge for developers and researchers would be to find how digital technologies are being introduced into the time economies of the household, and to support such emerging practices with tools that are designed for family members to enjoy using together, encouraging children's early use of technologies to be a sociable and talkative rather than a solitary occasion.

Conclusions

This paper set out to explore the potential links between research into children's learning with books and the design of interactive digital technologies for use by young children in the home. The value of the exercise is the potential it offers to future thinking about how such technologies are designed and used. It also offers some insights into how we might think about children's learning in the home as social and interactive with other family members rather than an 'instructional' educational model based on school practices.

We would conclude from this research that it is likely to be important for all those interested in developing digital technologies for use by young children in the home that they consider the following issues:

That the model of use that is imagined by designers and developers needs to be changed from one of solo use to one of shared use, which needs to support parent and child interactions, in which the resources are designed to be accessible to and enjoyable to both.

That there are opportunities for learning when resources are designed to be used in conjunction with families' organisation of time and activity, and that an enhanced understanding of informal learning and how families incorporate digital technologies into their routines may enhance learning opportunities with these tools.

That there is a requirement to fundamentally challenge the marketing language and dominant assumptions about learning that are used to promote digital technologies for learning in the home, and that ideas of playfulness, conversation, children as producers of texts and collaborators with others might be promoted.

For families too there are lessons from the literature on emergent literacy practices.

From this literature, we would suggest that families provide young children with opportunities to watch what older family members are doing with interactive digital technologies; that they find ways of enabling children to participate in what other family members do (for example, in taking photos, editing and displaying them on a computer screen).

It is also likely to be valuable for families to encourage children to imitate and extend these activities in their pretend play (for example by passing on old mobile phones to use for children's pretend phone calls); for families to find relaxed times in the day for shared playful activities with interactive digital technologies; and for families to share in children's conversation when using interactive digital technologies, following up their interest and questions.

Paper 2: What can the digital add to physical learning materials in early years numeracy classrooms?

Andrew Manches, Learning Sciences Research Institute, Nottingham University

Introduction

Walk into an early years classroom where maths (or many other subjects) are being taught and it would be surprising not to be surrounded by a wealth of physical learning materials, otherwise known as **manipulatives**. From alphabet letters to coloured cubes, these tools are there to help children learn new concepts in education.

Despite their longstanding familiarity in schools, however, there seems to be a lack of agreement over **how** or indeed **whether** manipulatives support children's learning generally, and mathematical understanding in particular[51]. At the same time, today, there are increasing calls to enhance these manipulatives with digital technologies[52,53].

The concept of digitally-enhanced physical learning materials is not new, as those familiar with **Roamer** (a commercial application of programmable educational robots called 'turtles') will recognise. However, now that even more sophisticated technology can be integrated into the smallest of devices, a wealth of new possibilities has been created. An earlier Futurelab publication, for example, has discussed the potential for handheld devices augmented by digital technology (tangible technologies) to support learning[54] and other work in the field has begun to put forward frameworks in this area[55,56].

There is, then, a need to understand how children learn early mathematics, what role manipulatives play in this learning, and to evaluate the potential for digital technologies to support learning in this area by enhancing such physical learning materials.

Outline of the paper

This paper will focus on mathematics taught to children in their first few years in school; more specifically numerical development in children between the ages of 5 and 8. It will briefly summarise the concepts children acquire in this area before looking at the context in which manipulatives, such as unit cubes or fraction tiles, are used and the possible mechanisms for how they support learning. Finally, these discussions will provide a framework to evaluate the potential for digital technology to augment manipulatives to support learning in this area.

The aim of this paper therefore is to provide the reader with an informed overview of how tangible technology might be designed to support a specific learning domain: number in the early years.

Key concepts in numeracy

Starting maths at school

Children do not start school without any previous experience of number. Through their interactions with the physical and the social world, children are familiar with numerical principles such as how quantities can be broken down and recomposed in different ways[57]. However, they may not know the mathematical language, both verbal and written, to reflect on and communicate these understandings. This language uses symbols to represent numbers and number operations (such as the word 'nine' to represent this quantity or the written sign '+' to represent combining quantities). At school, children will learn both new mathematical ideas and ways of communicating and representing these ideas.

What numbers actually mean

Children entering school are generally familiar with number words, but these may be recited as a simple sequence (**onetwothreefour…**), as they might be in a nursery rhyme. A key developmental step that children make is to grasp the **cardinal** nature of number. This is to say they need to understand that a number like 'seven' isn't just the word after '**six**' but refers to a quantity.

Knowing how number words refer to quantities is key to understanding the meaning behind the important numerical question 'how many?'. However, children initially remain dependent on counting objects (or pictures) to answer this question. For example, given a sum such as 5 + 3, children will count out 5 objects, then 3, then begin to count the total from 1 to reach the answer 8.

It is a significant step when children begin to use their understanding of number to calculate how many without having to count all objects. By starting to count from 5, children can count on 3 more to reach 8 far more efficiently. In this example, children demonstrate an understanding of the **cardinal concept**: that number words can be used to represent quantities.

Children then develop strategies that allow them to add quantities without the need for counting physical objects. For example, by using their fingers to represent an amount, children can count the answer more efficiently and eliminate the need for extra materials.

Developing number sense

Children learn to add and subtract quantities by counting up and down from certain numbers. But as their number sense develops they are able to use more flexible and efficient strategies to solve problems such as adding from the largest number first, or using their knowledge of number facts to simplify problems (eg using their knowledge that 6 + 6 = 12 to work out that 6 + 7 is one more than 12). With time, children will be able to use more remembered number facts to solve problems. However, children's capacity to learn and apply these facts is still rooted in their conceptual understanding[58].

More complex number concepts

At the end of the early years (7-8 years), children start to face more complex number concepts such as multiplication, multi-digit sums and fractions. Whereas children can learn procedures for solving these problems, it is becoming clearer that errors are more likely if these procedures are carried out without more conceptual understanding[59]. For example, the errors children make when adding multi-digit numbers (such as 57 + 65) highlight their difficulties in understanding how tens and units can be broken down and recomposed[60]. Consequently, various attempts have been made to identify what concepts are necessary for

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

understanding base ten so these might be supported. One framework identified counting, partitioning, grouping and number relationships as necessary prerequisites[61], illustrating how children draw upon their earlier numerical understanding to face the challenge of more complex concepts. It is clear that the foundations for children's mathematical development are established in the early years.

Summary of key concepts in numerical development

Children come to school with basic mathematical understandings that they will draw upon in school.

One major challenge for children is to map their understandings onto mathematical symbols, especially the use of written notation to represent specific quantities and operations.

Children use their cardinal number concept to develop more efficient strategies that remove a dependency on physical objects.

Children devise strategies to solve problems more efficiently using a 'flexible' sense of number to manipulate amounts.

Children can learn to draw upon their conceptual understanding of numbers when faced with more complex mathematical concepts and problems.

Although children develop strategies to calculate sums without depending on objects to count, it is not yet clear what role manipulatives might play in developing children's number sense. The next section attempts to address this by looking at how manipulatives are used and how they might support children.

Short introduction to manipulatives

One of the first advocates for 'hands-on learning' was the German educationalist Friedrich Froebel (1782-1852), better known as the founder of the 'Kindergarten system'[62]. To support learning, Froebel provided play materials, such soft yarn balls, now referred to as Froebel's gifts. This focus on child-centred learning was built upon by the work of Montessori (1870-1952)[63], whose hands-on approach to learning has given us the 'Montessori method', and who advocated the use of didactic materials designed to focus on specific skills, concepts or expertise.

The importance of physical materials in learning was supported by developmental theories which proposed a 'concrete to abstract shift' in cognitive development[64,65]. According to this view, young children's capacity for abstract thought was considered limited, hence a need to encourage the use of concrete models in learning.

However, the idea that cognitive development can be described as simply a shift from concrete to abstract has since been criticised[66]. It has been argued that not only might young children have more capacity for 'abstract' thought than previously realised[67], but we should also reconsider exactly how 'abstract' adult cognition is[68]. In this light, it is possible that children's numerical development should not simply be regarded as progressing from a dependency on concrete materials to the ability to think abstractly. In other words, rather than focusing on enabling children to work without manipulatives, we should examine how these concrete materials might help children to develop progressively more complex mathematical ideas.

Early years context

This paper focuses on the potential for manipulatives to support children's numerical development in the context of the early years' classroom. However, the meaning that children derive from manipulatives in this context will be greatly influenced by their prior experiences.

If we are to build on children's understanding gained out of school, it is important to recognise how this differs from mathematics taught at school. Children's prior understandings will have been gained through their interactions across a variety of settings, often represented non-verbally and learned incidentally59. In contrast, the mathematics of the classroom usually focuses on problems presented in hypothetical situations progressing toward problems presented without reference to anything concrete (eg 6 + 4 = __). Furthermore, mathematics in school is often presented in written form as part of the prescribed curriculum which the teacher is encouraged to follow.

It is possible that manipulatives provide children with learning experiences that they can associate more easily with their pre-school experiences. In addition, they might allow children to communicate and explore mathematical ideas without the more demanding physical requirements needed to control writing materials or a computer mouse. Consequently, physical materials in the classroom might provide an accessible medium for teachers and pupils to share meanings and explore ideas through different activities.

The way manipulatives are used, however, will vary from teacher to teacher. Differences include what type of activity is provided (how structured or exploratory is the activity), how often children have access to these materials, how many types of materials are used, and what attempts are made to link the objects to written numbers. These differences in use emphasise the difficulty in asking the question 'do manipulatives work?' and to an extent reflect the lack of consensus about if and how manipulatives actually support learning. Unsurprisingly, therefore, studies comparing learning with or without manipulatives tend to produce mixed results[69,70,71,72].

Ways in which manipulatives might support early numerical development

According to one author, "good manipulatives are those that aid students in building, strengthening and connecting various representations of mathematical ideas"[73]. Such manipulatives might help children to understand how we use numerical symbols, both verbal and written, to make predictions and communicate about the physical world, such as what happens if we combine two lots of apples or try to share some sweets between several people. This section will describe four ways in which manipulatives might achieve this: generating conceptual metaphors; creating actions; offloading concepts; and focusing attention[74].

Generating conceptual metaphors

It has been argued that numerical development can be thought of in terms of building layers of conceptual metaphors originating in our early concrete experiences[67]. Manipulatives such as cubes and tiles provide a concrete metaphor for the concept of number units. Therefore, it is possible that children's interactions with these objects support important numerical ideas such as how numbers can be compared, combined, grouped and partitioned in different ways.

Manipulative designs, however, use other features as metaphors for numerical concepts. For example, Cuisenaire rods use length (and colour) not quantity to reflect different number sizes. Pie pieces use segments as parts of a circle to embody the notion of fractions and Dienes blocks emphasise the base ten structure of number by using different size blocks.

Physical number lines can also be considered as conceptual metaphors for numbers. The use of equally spaced marks along a line uses length as a metaphor for increasing quantity. Importantly, this model can also illustrate written numbers along the line. Using psychological terminology, number lines simultaneously provide an iconic representation of numbers (through marks along a line) and a symbolic representation (through written numbers).

In contrast to the number line, physical manipulatives cannot provide a symbolic representation of number; you cannot attach a written number to blocks or tiles without potentially causing confusion. However, manipulatives allow for more physical interactions (enactive representation) and flexible designs might provide a better metaphor for the flexible nature of numbers. For example, although the number line might help children count up and down, manipulatives might provide a more accessible model for concepts such as how numbers can be grouped in different ways[75].

The advantages of actively manipulating objects were argued in a recent paper entitled 'Physically Distributed Learning'[76]. The paper proposed that by physically changing the environment, individuals can change how they interpret the environment, and hence learn. Using fractions as an example, it was argued that by physically manipulating materials children could develop their concepts of fractions. This theory was supported by studies showing how children who used manipulatives solved more fraction problems than children who simply annotated copies of squares.

At present, it is difficult to conclude from research which external models, such as cubes or number lines, most support children's number development. But two important issues have been raised: first, how can different mathematical concepts be represented most clearly; and second, how can children's understanding using models be linked to an understanding using symbols.

We need to identify in a systematic and rigorous fashion how different mathematical concepts can be represented using different types of materials. This analysis would also help identify concepts that are not so easily embodied physically such as place value. However, it is important to reiterate the need to consider how physical representations are being mapped to more 'formal' maths; what has been referred to as the 'connecting phase' of mathematical learning - "constructing strong connections among ways of thinking about concrete situations and conventional mathematical language and notation"[77].

Virtual manipulatives have demonstrated how technology can help map children's actions with concrete representations to symbolic representations. Virtual manipulatives are virtual objects presented on screen in computer programs that can be manipulated as objects using a mouse or keyboard[78]. However, because these objects can be enumerated by the computer, symbolic representations (such as written numbers or recorded verbal labels) can be provided simultaneously. Virtual manipulatives, therefore, can provide children with immediate feedback from their actions as well as activities which can be described as playing a tutoring role[79].

It is not surprising, therefore, that virtual manipulatives have generated considerable interest both commercially and academically[80,81]. However, they raise an important question: is anything lost when objects are manipulated on screen as opposed to physically? In a virtual world, two-dimensional objects are manipulated indirectly through small movements using a mouse or keyboard. Therefore, it is necessary to consider any potential benefits lost from the physical actions generated when interacting with real rather than virtual objects.

Generating actions

When children use manipulatives they are able to use both their hands and fingers to pick up and arrange individual or groups of pieces in the space around them. These physical actions can be carried out relatively quickly and with little cognitive effort. As a result, manipulatives provide a way for children to explore quantitative relationships through simple, direct physical actions.

When children interact with manipulatives, they create gestures that can support their thinking in certain tasks. For example, by touching pieces, children are able to keep track of how many pieces they have counted as well as maintain one-to-one correspondence between the pieces and the number words[82].

It is also possible that the actions children create when using manipulatives, such as moving pieces together when adding, or tapping fingers when counting, relate to the gestures that are sometimes used in the absence of materials. Indeed, it has actually been shown that the use of manipulatives can increase gesture use[83], and one recent study has looked at this with respect to fractions[69]. This study investigated young adults' concepts of fractions and recorded the gestures used when describing fraction concepts. Many gestures were observed and some were judged to be reflective of previous experiences using manipulatives. This raises the possibility that the adults' concepts might have developed from actions used in learning. The idea that motor actions are integral to cognition is supported by recent arguments that we have a separate memory system for encoding motor actions (as well as verbal and visuospatial memory systems)[84].

The role of gestures in supporting thinking has received considerable attention in the last decade[85,86,87,88]. It was shown in one study how by gesturing, children were able to 'offload' cognitive resources in explaining maths problems, allowing them to remember lists of letters or words[89]. Gestures can also be used as a measure to assess a child's understanding[90] and have been shown to support children's understanding when used by the teacher[91].

The relationship between gesture and thought has been related to an emerging research area called Embodied Cognition[92]. Embodied Cognition refers to how our thoughts are inseparably linked to the physical world in which they developed and then were applied. Accordingly, gestures have been interpreted as products of the embodied nature of our thoughts.

The ideas of Embodied Cognition are far from being universally accepted and the relationship between gesture and cognition is still unclear. However, the possible importance of the physical world in our thinking, and more specifically the possible role of physical actions in developing concepts which can result in the later use of gestures, do suggest a need to understand more clearly what role the actions generated from manipulatives might play in learning.

Offloading concepts

'Offloading' refers to the ways in which we can make tasks more manageable by transferring part of the workload onto the environment (for example, by using a calculator to calculate sums). Manipulatives allow children to offload their representations of quantities onto an external model. Individual pieces can represent different amounts (such as ten, or a fifth) and the way they are arranged spatially can illustrate different number relations. For example, a group of 12 pieces in four groups of three might represent four lots of three, or four quarters of twelve. As a result, this arrangement would allow children to model calculations such as three lots of four, 12 – 3, or a quarter of 12, and consequently support children in calculating the answer. By creating small discrete groups of objects, manipulatives may also help children to determine the number of pieces. It has been shown that children and adults are able to enumerate up to around five objects remarkably quickly[93] (a process referred to as subitising) and that this may be done by some perceptual process distinct from counting. This area remains controversial[94] but may possibly have implications for how physical models can provide spatially discrete sets of small quantities when exploring number relationships.

By offloading a task onto manipulatives, children might be able to free up important cognitive resources that they can use to reflect on the mathematical ideas being modelled. For example, the perceptual similarity of 7 + 3 and 3 + 7 may help children understand how numbers can be added in any order. Unfortunately, the extent to which children may or may not reflect on these meanings is still unclear. Children may be able to use manipulatives to externalise their ideas but have difficulties in using this external model to internalise new concepts.

The last paragraph raises an important point: manipulatives might help children solve certain problems without necessarily helping them learn how to solve these problems internally. It is possible, however, that children's internal models actually reflect the concrete models they have been exposed to[95], a view that is supported by studies of expert abacus users[96] as well as the relatively recent finding that we possess an internal number line which orders numbers according to the direction we have learnt to read[95]. Indeed, this internal number line may help explain the reported success of a physical empty number line used to support children with multi-digit addition and subtraction[97].

However, it is not only unclear how internal models develop from different concrete experiences, but also how these models might vary, and which of these models may be more supportive in solving mathematical problems. Therefore, the challenge remains for research to understand more about how children develop their internal representations of numbers and how these might possibly be developed through using manipulatives.

Focusing attention

Manipulatives can be more or less concrete. This is to say they can appear more like everyday objects such as coins, biscuits or sweets, or more generic like cubes, tiles and pie pieces. The manipulatives predominantly referred to in this paper are those most commonly used in classrooms: more generic designs. The aim of this is to reduce the features that might distract children and hence focus their attention on certain mathematical concepts. The use of less concrete manipulatives is supported by the finding that we are more able to transfer knowledge gained to other similar problems than when using more concrete materials[98]. Clearly, it is not possible for physical objects to be completely generic; they will have colour, shape and possibly ways to adjoin them. Unfortunately, however, it is still unclear what influence these features have on children's attention.

It is also possible that, by providing an external model, manipulatives may support a shared focus of attention and thereby foster communication between children and teachers[96]. However, this raises an important question: how transparent are number concepts to children when using manipulatives? Can we assume that children easily understand that one piece represents 'one' or a long piece can represent 'ten'?

Arguments against manipulatives

The great difficulty we have as adults in trying to assess how well manipulatives represent different mathematical concepts is that, unlike children, we have already learnt these concepts. For example, Dienes blocks represent base ten by using different sized blocks to refer to units, tens and hundreds, but our understanding of base ten and place value might lead us to overestimate how accessible these concepts are from these materials.

Manipulatives are intended to represent number relations such as units or fractions, and a central criticism has focused on how easily children perceive this representation[99]. According to one theory, manipulatives have two representations: a symbolic representation (of number) and a representation based on the child's personal experiences with similar materials[100]. For example, unit blocks may be intended to symbolise 'one' but may be more easily interpreted as building blocks. As a result of this conflict in what different physical materials represent, manipulatives may not be used in the way the teacher intended, and possibly hinder rather than support learning.

Arguments against manipulatives, therefore, centre on our uncertainty about how much support is needed to help children map concepts embodied in physical materials to rules that govern the verbal and written language of more formal mathematics. Returning to the Dienes blocks example, success using these materials was reported in terms of supporting children's understanding of multi-digit calculations but only as part of a thoroughly designed intervention focusing on mapping these materials onto number problems[72]. Important questions to ask, therefore, concern how much support is needed to help children understand how manipulatives represent number concepts and to then reflect on this understanding to support problem solving in the absence of these materials. The level of support needed will ultimately determine the efficiency of manipulatives in comparison to other forms of teaching interventions.

Conclusions about manipulatives and the arguments against them

Manipulatives might provide a way to bridge the gap between children's concrete experiences and the symbolic world of maths. Generally, their designs are simple, reflecting the intention to focus children's attention on key mathematical principles. Manipulatives are physical objects allowing children to explore different concepts and share ideas in physical space. However, because mathematical symbols are used to refer to collections of quantity and operations carried out with these collections, it is potentially confusing to actually inscribe these symbols (such as '3' or 'divide by') onto individual objects. Instead, other resources are needed to help children map representations of quantity, afforded by manipulatives, to the symbolic language, both written and verbal, of mathematics.

Having evaluated the role of manipulatives in this area, it is now possible to start thinking of ways that digital technology might build on the learning mechanisms identified and address the criticisms made against these materials. Doing so might identify design ideas that have the potential to support children with number in the early years. This possibility is explored in the following section.

Augmenting manipulatives with digital technology

The increasing use of technology in schools is testament to our confidence in the potential for 'the digital' to support learning. This has generally taken the form of an increase in the number of computers and various software titles. However, the more recent ability to integrate technology seamlessly into smaller devices has created new possibilities for educational materials: tangible technologies. **Roamer** provides a recognisable example of how such technology can be integrated into physical learning materials. However, smaller and more sophisticated devices are becoming possible today and Roamer itself has evolved with the advance of technology; instructions can now be sent wirelessly from a desktop computer using Bluetooth.

Research into the use of tangible technology to support abstract concepts like number is in its infancy. Indeed, this was emphasised in a recent framework for understanding manipulatives[100]. This framework distinguished between products and research that focused on 'real life' processes such as Lego bricks (referring to them as Froebel-inspired manipulatives) and those supporting more abstract concepts such as fraction tiles (referred

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

to as Montessori-inspired manipulatives). The authors use this framework to highlight a gap in the research field specifically in the area of the use of digital manipulatives to focus on more abstract concepts.

The projects **Flowblocks** and **Systemblocks**[101] attempt to address the gap in this area. Flowblocks, shown below, were designed to model concepts related to counting, probability, looping and branching. The system consists of blocks which sequentially display a light, giving the appearance of the light 'flowing' through the blocks. Different blocks allow children to explore the dynamic system, for example, by speeding up and slowing down the flow. There is a counter block which displays the number of times light has flowed through.

The authors report success with Flowblocks in terms of children's engagement. Unfortunately, no information is provided on the important question of what the children actually learnt. Answering this question with empirical evidence is difficult, requiring more time and attention to other effects on learning such as the amount of adult time provided. However, despite the suggestion that Flowblocks support counting it is not clear how these materials support children's understanding of this concept.

In this paper I want to argue that there is a need to build designs around our knowledge of how children's understanding develops and the context in which this occurs. Consequently, I will attempt to identify how digital technology might augment manipulatives used in the early years classroom to support numeracy using the key concepts from the previous section.

Generating metaphors

Teaching Table[101] is a recent design, focusing specifically on early maths skills. The device consists of a table where children can place tiles with numbers on them. The table has a wireless connection with a graphical device and built-in speakers, and so can provide a range of activities (ordering numbers to ten, finding the biggest number) and, by recognising the tiles children place on the table, provide feedback.

The teaching table highlights the potential to integrate different representations of number though the use of sound and digital displays. It also demonstrates the potential for

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation

technology to provide a tutoring role. However, despite being physical in nature, quantity is not represented physically, only through written numbers inscribed on tiles. Consequently, this design may help children practise calculations but it does not provide a quantitative metaphor for number to help children map this to number symbols.

There is an opportunity, therefore, to use digital manipulatives to help children to map their early understanding of quantity to the mathematical symbols to help link two forms of representation (enactive and symbolic). Because technology now enables physical objects to 'communicate' with each other, it is possible for displays to enumerate how many blocks are in a certain area or adjoined. Such a display could be separate or integrated into the materials and would allow children to not only see both representations simultaneously, but provide them with a means to explore how this changes as they actively manipulate the materials.

By linking objects to symbols, certain numerical concepts are made explicit, such as how numbers represent the total, how this does not change depending on the order or arrangement of objects, how adding one and taking another away will not change this total, or how quantities can be decomposed into different number bonds.

It is also possible to envisage ways that digital features can be used to allow the same materials to embody a wider range of numerical concepts, consequently allowing teachers to scaffold children's understanding by choosing what features are available for different activities. Table 1 illustrates how different models can be used to scaffold children's understanding of place value. Digital technology could integrate features that allow these models to be embodied in the same materials, for example by using sound or colour to emphasise collections of ten, introducing a specific colour to represent a 'ten piece', or the inclusion of a position rule between pieces to highlight the order importance of place value. Furthermore, if children's internal models of number are developed by external models as was previously suggested, it is possible that a more comprehensive model afforded by digital technology might help children develop more flexible internal models to solve problems in the absence of materials.

For copyright reasons page 30 has been removed; the table on this page can be requested from the author or the report can be viewed in full on the Futurelab website: http://www.futurelab.org.uk/openingeducation .

Digital manipulatives, like physical manipulatives, are manipulated in real physical space. This affordance was previously discussed in contrast to virtual manipulatives which are manipulated on a computer screen with more indirect actions using a mouse. The few studies comparing physical and virtual manipulation have yet to reveal any significant differences on learning[82], however, they have tended to focus on older children and physics rather than maths. Clearly, it is important to establish the importance, if any, of physical manipulation across different tasks. For example, a recent study looked at how well people could remember the content from ten newspaper summary articles when the information was either represented on screen using icons or attached onto real physical blocks[103]. It was found that by arranging the blocks in real space, people were not only more likely to remember the layout but also could use this to help remember the content of the articles.

Digital manipulatives can be touched, rearranged, added together and partitioned directly, and novel designs should attempt to maintain the range of actions that are relevant to the mathematical ideas children are exploring. However, it is also possible to envisage ways that technology might even be used to emphasise the relevant actions children make. Sony's digital pet dog Aibo (reported in [57]) uses a touch sensor to encourage the action of patting the dog on the head. Similarly, digital effects could be used to encourage children to explore the results of certain actions such as tagging items when counting or changing the size of a collection.

Offloading concepts

Smart Blocks[104] is a tangible design that allows children to explore the relationship between surface and volume by manipulating blocks and seeing the resulting change in values displayed on a computer. Children can explore the relationship more easily by focusing on how changes in one value relate to another rather than spending time and effort on the calculations themselves. Similarly, by removing the need to count objects, digital manipulatives might allow children to explore numerical relationships more easily.

There may be times when we want children to count or do not **want** to provide them with values immediately. Indeed, it has been shown that integrating small barriers can actually encourage people to reflect more on a task when using technology[105]. This can be integrated as a design feature, for example delays in displays or a need for specific actions to obtain 'the answer'. If teachers were given control over these features, this might then allow them to vary children's interactions with digital manipulatives.

Focusing attention

In contrast to most everyday materials, existing manipulatives have simple designs that help focus children on key mathematical concepts. It is important to apply this principle to novel designs. Although digital effects such as flashing lights and sounds can be added to initially engage children, these effects will lose their novelty and may simply distract children from the key concepts we want them to learn. It is important, therefore, that digital effects are used to focus attention on key concepts. For example, effects could be used to emphasise the significance of collections of ten.

Teachers are generally expert at asking questions and attempting to focus children's attention on important concepts. As the Teaching Table as well as numerous educational software titles show, it is possible to present questions digitally, providing structured activities without the need for the teacher's input or use of worksheets. But digital technology cannot provide the same level of interaction and open questioning that a teacher can. Nor do software or systems such as Teaching Table generally allow for less structured exploration of materials.

By designing digital manipulatives that can be used in both unstructured **and** structured ways, for example simple blocks that can communicate remotely to a laptop, it is possible to provide materials that afford the flexibility for teachers to choose how to use them. An ideal design might be one which was simple enough for teachers to feel confident using the materials as a communicative tool but sufficiently complex to provide independent educational activities for children.

Final conclusions

Young children develop ways to add and subtract numerical quantities without the need for materials. However, as their number sense develops they are not only able to tackle more complex problems but also to devise more flexible strategies to solve problems more efficiently. It is possible that appropriately designed manipulatives could give children access to concepts at an early age and also help them develop stronger foundations for later numerical development.

Manipulatives have been designed to embody abstract concepts using features such as colour, size and shape, although the ease with which children grasp these metaphors has been questioned. However, we now have the possibility of using digital technology not only to broaden the ways in which we can highlight different concepts but also to help bridge children's understanding of the relationship between physical materials and numerical symbols.

Clearly, we cannot predict exactly how well novel designs will support specific concepts and so it is essential to examine their effect on learning within the classroom context. Assessing the success of materials must go beyond descriptions of how well they initially engage children. This is not to say that engaging children is not important. Indeed one vision of digital manipulatives refers to "objects that combine the cognitive benefits of a scientific demonstration with the emotional resonance of a birthday present"[54]. Unfortunately, like birthday gifts, designing for fun can risk fading novelty effects.

The success of materials, however, will ultimately depend on how they are used by the teacher. This paper has aimed to respect this by focusing on curriculum-relevant number concepts and examining how children's understanding of these concepts might be supported by using technology to augment materials that teachers are already familiar with.

Manipulatives have been used as tools by teachers to help children access a level of maths that has taken centuries to develop culturally. It is not unreasonable to envisage how in an age of great technological advance we might develop materials that can achieve this more proficiently.

Paper 3: Reflections on research and design for early years digital technology

Rosamund Sutherland, Claire O'Malley, Lydia Plowman, Andrew Manches, and Sarah Eagle.

The two papers presented previously have engaged with relevant literature as a first stage in generating new ideas, designs and issues for consideration in the potential development and use of digital technologies to support early years learning. The first paper was concerned with understanding the role that digital technologies play in shaping interactions between parents and young children in the home, the second with understanding the role of digital manipulatives in early years learning of numeracy in school.

This paper takes a step back and discusses more generally some of the issues around the relationship between educational research and the design of new technologies for early years. We consider some of the common themes that have emerged from the two papers, making conjectures about what might have influenced the design of software for this age range. Finally we discuss the key messages for all of those interested in researching and developing digital technologies for early years learning – both from general principles and from the specific examples discussed in this paper.

Designing for intimate, shared interactions

The papers by Sarah Eagle and Andrew Manches cover different learning domains (literacy and numeracy), different age groups (under-fives and early primary) and different contexts for learning (the home and the school). However, there is a common theme that emerges from their papers. The paper by Eagle argues that pre-school print literacies (for example storybooks) tend to be designed for shared use within the family, providing many opportunities for children to participate in the shared construction of meaning. Within the family, the intimacy of the end-of-the-day bedtime story reading between children and parents creates a key context for learning to read and learning about the structure of stories, the turn-taking around story-telling and listening, and an appreciation of audience and genre. Manches argues in his paper that there is a long history of designing non-digital manipulatives for learning numeracy in school (for example Dienes blocks) and that it is the close – even huddled[106] – work between children and teachers around physical objects that supports activities such as counting and partitioning – key skills in learning early mathematics.

Eagle notes that interactions between children and parents in the hurly-burly of the daytime are focused on the here and now, and the practical business of daily talk directed towards practical activities. By contrast, the bedtime story sees parents and children thinking and talking beyond the here and now. When they do this, parents are taking on a pedagogical role, but may not be aware that they are teaching as they do this instinctively. Whereas parents' roles as actors and agents in children's learning experiences are acknowledged by authors and designers of children's books[107], it is not clear that designers of digital technologies for pre-school children take account of the potential involvement of family members when young children interact with software. Manches takes as his context the formal classroom setting, and notes the importance of more **informal** interactions (ie non-prototypical teaching interactions) between teachers and children in gesturing and meaning-making around physical blocks, rather than 'teaching from the front'.

The interactional dynamics of intimate shared moments between children and adults around shared artefacts is clearly key here. Yet the design of educational technology seems to overlook such issues, and, even in the research world, little is written about this, with some important exceptions[108].

How then should we design intimate technologies that support sharing between pairs and small groups - adults and young children in this case?

We know how to design individual interactions (more or less well) and how to support large groups (both co-present in a classroom and remotely on the internet) but little research has been carried out on designing for the rich context of intimate shared encounters with technology.

The importance of physicality

Both papers draw attention to the importance of physical interaction in the different learning contexts that they describe.

Manches' work highlights the physicality of the artefact and its potential to influence children's physical exploration of mathematical relationships that generate conceptual understanding. Through picking up, handling, sorting and re-ordering of manipulatives children are able to explore quantitative relationships. Recent work suggests that the physical actions involved in rearranging pieces or tapping them when counting are linked to the way that children develop facility with thinking about number, and Manches suggests that if this is the case, augmenting manipulatives with technology might assist children's learning through emphasising the relevant actions children make.

In the case of the bedtime story, children learn about books, stories and decoding print through the nonverbal gestures of the story reader. Children are encouraged to point out things, nonverbally. This is all accompanied by gazes between adults and children to gauge attention, share jokes, and check understanding and levels of interest. It is an intimate interactional dance involving talk, gaze and gesture. Computer-based reading experiences do not easily mediate these interactions to the same extent as physical books. Does this mean that there is no place for interactive technologies in this context? Not necessarily. Eagle's paper showed how, in this context, reading becomes an active, constructive and playful activity; the physical actions of pointing things out, and turning pages, are important aspects of joint attention and dialogue in making sense for each other of a shared experience with the printed word. Later on in the paper she discussed the potential of new technologies, such as sharing digital photos, creating home videos, blogs and web pages, to transform literacy into a more engaging, interactive and constructive activity, and to prepare young children for the kind of digital literacy they might encounter at school. We have already witnessed the emergence of interactive CD Roms, which might be regarded as books augmented with technology to make them interactive in their own right, creating the possibility for shared construction and interpretation of stories[109]. Software which allows children to make changes in stories with their own printed words, pictures and sounds is also available, although aimed at kindergarten and primary schools rather than domestic settings.

The questions to ask are: Can the interactions that children have with digital versions of literacy materials replace the social, and often non-verbal, interaction between young children and others? Do the two kinds of interaction complement and/or enhance one another? What can designers do to optimise the kinds of interactions which provide young children with rich opportunities for learning?

Leaving space for meaning making

Another theme that emerges is the importance of leaving space for meaning-making in the interactions between young children, adults and digital technologies. Typically there are two contrasting approaches in terms of pedagogical activities supported by traditional educational software – drill-and-practice versus open exploration. Increasingly research on the role of digital technologies for teaching and learning across the primary and secondary phases of schooling points to the importance of a more nuanced approached to pedagogy which includes whole-class interaction, group work and individual work[110]. This points to the role of the teacher in both orchestrating such interactions and supporting meaning-making that is related to the intended learning.

The role of the teacher (or more knowledgeable other) in supporting meaning-making as young children interact with digital technologies is arguably even more important in the early years. However in early years education the emphasis has always been on open play and exploration. Plowman and Stephen have convincingly shown that when digital and PC-based technologies are introduced into the early years of schooling, teachers interpret an emphasis on play as implying that young children should be allowed to interact with software without intervention from the teacher[111]. Their research shows that young children often do this on an individual basis, that activities tend to be focused on desktop computers rather than other technologies, and that periods of social interaction tend to be very short.

This again points to the importance of designing software for early years education that incorporates appropriate scaffolding and provides space for meaning-making and opportunities for shared interactions between young children and adults that build on the child's input. Interestingly this was the intention for how Logo (and the Roamer) would be used in the classroom, but the Logo[112] environment was potentially too open-ended for teachers to make sense of with respect to the curriculum, and when it was taken up in the classroom children tended to be left with the responsibility for too much sense-making for themselves. In fact the history of the use of digital technologies in education has shown that whether software is designed from a drill-and-practice perspective or from an open-exploratory perspective, teachers tend to delegate their responsibility for teaching to the computer in ways that are qualitatively different from their use of non-digital technologies in the classroom. The computer is either viewed as a personal tutor or as TV-type media used as a reward, both of which potentially make the role of the teacher redundant.

The situation is not that dissimilar in the home. Whereas parents and adults interact with pre-school children around non-digital technologies such as books and games, leaving space for sense-making on the part of the child, they take on a different role when children are interacting with 'drill and practice' toys and software. Eagle's ongoing research is showing that in these situations adults define their role as teaching the child to follow the instructions, and do not continue to be involved after some mastery has been achieved.

Old habits and new possibilities in the design of early years digital tools...
We have argued above that early years' learning is inextricably linked to shared physical and social interactions between young children and adults.

We also want to argue that most designs of digital technologies for the early years are, implicitly at least, aimed at supporting individual interactions with technology. They are designed for the individual child, interacting in a fairly solitary fashion with the software. This is the case for both the more open-ended software which has been influenced by a Piagetian constructivist view of the child as a 'lone scientist' interacting with the physical world, and for the drill-and-practice type software which has been implicitly influenced by behaviourist theories of learning.

For example, one of the most successful digital technologies for teaching early primary mathematics is RM Successmaker Enterprise. There is, arguably, much evidence for its effectiveness in teaching primary maths. Yet its marketing materials represent a very specific idea of what counts as good learning practice:

> "Successmaker delivers individualised learning in maths, reading, writing and spelling for students aged 5 to 14 years. Each student has a learning programme continuously tailored to personal needs; all students progress at their own level and pace and are free to achieve within their own private learning space."[113]

A simple search through educational software titles to support reading in the early years of the primary school shows that a large number are similarly self-declared drill-and-practice activities designed for individual use. Even if teachers might use such software with interactive whiteboards (and many of the current titles do support this), it is hard to see how they can be made to support collaboration without a good deal of creative effort on the part of teachers.

This all seems quite remote from the picture painted by Eagle and Manches of intimate interactions amongst children, parents and/or teachers, around genuinely shared activity.

We would argue that this reliance on the model of an individual user is derived from popular conceptions of what counts as (and what can be marketed as) the preferred model of learning, and from the reliance on the 'PC' as the standard hardware platform.

When we look at the model of learning promoted in much software marketing materials and design, we see an image of an individual child, interacting in a fairly solitary fashion with software that provides progressively more challenging progress. Arguably, this idea of the end-user is shaped by a popular conception of learning in which one-to-one teacher/learner interaction is considered to be the most effective situation to be strived for, a sort of 'personal tutor' set-up, implicitly reflecting the privilege of a private governess. With a concept of the

Image removed for copyright reasons. The report can be viewed in full on the Futurelab website:
http://www.futurelab.org.uk/openingeducation

'personal tutor' as the popular ideal for a learning relationship, there is little surprise that tools should be designed for individual interactions.

Such 'individualised' software is also designed largely for use on standard PCs. This makes sense from a marketing perspective – many, if not most, homes have a PC or laptop; schools have PCs and interactive whiteboards. There are also policy and institutional drivers here – for example, schools in England are given e-Learning Credits to purchase educational software to suit the hardware platforms that they (and the policy makers) have invested in. The issue is that PCs were of course originally designed to support office, desk-based, use, and interactive whiteboards have become popular because they fit very well with the traditional methods of whole-class teaching from the front. In other words, there are historical, institutional and cultural barriers that mitigate against designing interactive technologies that might otherwise be more fit-for-purpose in terms of learning in the early years.

These historic institutional and cultural barriers, and the dominance of marketing departments over research departments, tend to mitigate against designing interactive technologies that support the sorts of shared, intimate and playful interactions that might otherwise be more fit-for-purpose in terms of learning in the early years. (The Roamer, referred to by Andrew Manches, is probably the one exception of an enduring educational technology that is in the spirit of recent research developments in the design of tangible technologies.)

At the same time, very young children are also rarely thought of as the primary users of any digital technologies. Indeed, they are expected to adapt to products that have not been designed with them in mind. This is clearly the case with the standard desktop PC and keyboard. Equipment produced for adults often has inappropriate physical and cognitive ergonomics for children, particularly for pre-schoolers. However, design for young children is not simply a matter of scaling down the hardware, as pre-school users are not scaled-down adults but have specific requirements of equipment, such as robustness and mobility. Generally, play is seen as an embodied and physical activity (dressing up, sand and water play, tumbling and climbing, for instance) rather than a digital one and technology is seen as having explicitly educational rather than play value in pre-school settings.

What is missing in the design of much software for the early years is an awareness that learning derives from a process of interaction with both the social and the physical world, with parents and teachers being key actors in children's learning experiences. What is also missing is an awareness of the importance of the more informal and intimate interactions between young children and others around shared physical artefacts. Whereas we recognise that software, regardless of its design, can be used in many different ways, we suggest that if it (or its marketing) suggests 'individual interaction' then parents and teachers are less likely to sit alongside the young child, engaging in shared activity.

But there are starting points that researchers and developers might explore to challenge these assumptions. For example, even with the traditional PC as a starting point, designing interactive educational software doesn't have to stick with individually based interactivity. It is not difficult to design software for multiple users, even if they share a single screen – for example, the KidStory project was concerned with developing software to support collaborative shared storytelling running on standard PCs by using more than one mouse[114]. Similarly, while the conventional reliance on screen-based text and graphics presents a barrier to interaction for pre-school children, this could be overcome by products designed with tangible (ie touchable) interfaces. And the same developments in tangible interfaces could also serve to erode the distinction between digital and physical play.

A striking example of the potential of designing for a different model of user interaction is in evidence in the leisure and entertainment fields. Leisure and entertainment technologies are far more diverse in their physical instantiation and are usually shared, mobile, and involve physical interaction – eg games consoles, Wii remotes, pressure pads as in Dance Revolution, robotic kits as in MindStorms, and so on. For children of this age, toys are also an important, but largely overlooked, source of exposure to technology in the home. Most young children play with toys that simulate mobile phones, laptops and games consoles, and current examples include V-Tech Smile and Disney Plug-n-Play games consoles and Leapster handheld game systems. Many of these products are simultaneously marketed as toys for play and as technologies that support learning[115].

Recently, we have seen the proliferation of toys and other 'edutainment' products aimed at pre-school children and their families that combine opportunities for digital and manual play through new forms of physical artefacts with tangible interfaces. These products use familiar forms, such as toys, dolls or construction bricks, but they are computationally enhanced. They are not televisual or text-based, do not use a desktop metaphor and do not rely on a keyboard or mouse input. These toys are not tethered by cables in the same way as personal computers and so are portable. They can respond to a child's attention and be wearable, cuddly or robotic.

The quality of design of such products is clearly at the heart of their suitability for purpose and how attractive they are to children. If anything, the consequences of poor design are more serious for this age group than others[116].

We would, therefore, like to finish with a question and a challenge to researchers and designers:

What might happen if we turned the assumption of the lone child placed in front of a PC screen on its head and designed instead for inter-generational, shared participation in play with tangible artefacts?

And we would be very interested in hearing (and perhaps seeing and trying out) your responses.

References

1 Snow, C (2007). What counts as literacy in early childhood? In K McCartney and D Phillips (eds) Handbook of Early Child Development. Oxford: Blackwell

2 Barton, D and Hamilton, M (1998). Local Literacies: Reading and Writing in One Community. London: Routledge

3 Street, B (1984). Literacy in Theory and Practice. Cambridge: CUP

4 Scribner, S and Cole, M (1981). The Psychology of Literacy. Cambridge, MA: Cambridge University Press

5 Rogoff, B, Mistry, JJ, Göncü, A and Mosier, C (1993). Guided participation in cultural activity by toddlers and caregivers. Monographs of the Society for Research in Child Development, 58

6 Rogoff, B (1990). Apprenticeship in Thinking: Cognitive Development in Social Context. Oxford: Oxford University Press

7 Teale, W and Sulzby, E (1986). Emergent Literacy: Writing and Reading. Norwood, NJ: Ablex

8 McNaughton, S (1995). Patterns of Emergent Literacy: Processes of Development and Transition. Oxford: Oxford University Press

9 Department for Education and Science (1975). A Language for Life (Bullock Report). HMSO

10 Meek, M (1991). On Being Literate. London: Bodley Head (p110)

11 Cairney, TH (2003). Literacy in family life. In N Hall, Larson and J Marsh (eds) Handbook of Early Childhood Literacy. London: SAGE

12 Ninio, A and Bruner, J (1978). The achievement and antecedents of labelling. Journal of Child Language, 5(1): 1–15

13 Wells, G (1986). The Meaning Makers: Children Learning Language and Using Language to Learn. Portsmouth, NH: Heinemann

14 Snow, C (1993). Families as social contexts for literacy development. In C Daiute (ed) The Development of Literacy Through Interaction. San Francisco: Jossey Bass

15 Walsh, M (2003). 'Reading' pictures: what do they reveal? Young children's reading of visual texts. Reading: Literacy and Language, 37(3): 123-130

16 Lewis, D (2004). A word about pictures. In Grainger, T (ed) Routledge Falmer Reader in Literacy. London: Routledge

17 Cochran-Smith, M (1984). The Making of a Reader. Norwood, N.J: Ablex

18 Sulzby, E (1985). Children's emergent reading of favourite storybooks: a developmental study. Reading Research Quarterly, 20, 458-481

19 Leseman, P and de Jong, P(1998). Home literacy: opportunity, instruction, cooperation and social-emotional quality predicting early reading achievement. Reading Research Quarterly, 33(3): 294-318

20 Greenhough, P and Hughes, M (1998). Parents' and teachers' interventions in children's reading. British Educational Research Journal, 24(4): 383-98

21 Bus, A, Leseman, P and Keultjes, P (2000). Joint book reading across cultures: a comparison of Surinam-Dutch, Turkish-Dutch and Dutch parent-child dyads. Journal of Literacy Research, 32: 53-76

22 Hannon, P, Weinberger, J and Nutbrown, C (1991). A study of work with parents to promote early literacy development. Research Papers in Education, 6(2): 77-97

23 National Reading Campaign (www.nationalliteracytrust.org.uk/campaign/indexey.html)

24 Peers Early Education Partnership (www.peep.org.uk)

25 Nichols, S (2000). Unsettling the bedtime story: parents' reports of home literacy practices. Contemporary Issues in Early Childhood, 1(3): 315-328

26 Cloran, C (1999). Contexts for learning. In F Christie (ed) Pedagogy and the Shaping of Consciousness: Linguistic and Social Processes. NY: Continuum

27 Dickinson, DK and Tabors, PO (2001). Beginning Literacy With Language: Young Children Learning at Home and School. Baltimore: Paul Brookes Publishing

28 Lane, H (2008). Let Me Tell You a Story… The Guardian, 15 March. Available at: lifeandhealth.guardian.co.uk/family/story/0,,2265583,00.html (accessed 3 April 2008)

29 Murphy J (1986). Five Minutes' Peace. London: Walker

30 Murphy, J (1999). All in One Piece. London: Walker

31 Murphy, J (1989). A Piece of Cake. London: Walker

32 Lewis, C (1984). Searching for the master touch in children's picture books. Children's Literature in Education, 15(4): 198-203

33 Nikolajeva, M and Scott, C (2000). The dynamics of picturebook communication. Children's Literature in Education, 1(4): 225-239

34 Meek, M (1988). How Texts Teach What Readers Learn. Stroud: Thimble Press

35 Rodari, G (1996). The Grammar of Fantasy: An Introduction to the Art of Inventing Stories. New York: Teachers & Writers Collaborative

36 Dresang, E and McClelland, K (1999). Radical change: digital age literature and learning. Theory into Practice, 38(3): 160-167

37 Freebody, P (1992). A socio-cultural approach: resourcing four roles as a literacy learner. In A Watson and A Badenhop (eds) Prevention of Reading Failure. Sydney: Ashton-Scholastic

38 Unsworth, L, Thomas, A, Simpson, A and Asha, J (2005). Children's Literature and Computer Based Teaching. London: McGraw-Hill/Open University Press

39 Hannon, P, Morgan, A and Nutbrown, C (2006). Parents' experiences of a family literacy programme. Journal of Early Childhood Research, 4(1), 19-44

40 Plowman, L and Stephen, C (2007). Guided interaction in pre-school settings. Journal of Computer Assisted Learning, 23(1): 14-26

41 Mackey, M and McClay, J (2000). Graphic routes to electronic literacy: polysemy and picture books. Changing English, 7(2): 191-201

42 Torr, J (2004). Talking about picture books: the influence of maternal education on four-year-old children's talk with mothers and pre-school teachers. Journal of Early Childhood Literacy, 4(2): 181-210

43 Torr, J (2007). The pleasure of recognition: intertextuality in the talk of preschoolers during shared reading with mothers and teachers. Early Years, 27(1):77-91

44 Buckingham, D and Scanlon, M (2003). Education, Entertainment, and Learning in the Home. Buckingham: McGraw-Hill/Open University Press

45 Strommen, EF (2004). Play? Learning? Both… or neither? Paper presented at the Annual Meeting of the American Education Research Association, San Diego, CA, 12-16 April. Available online: www.playfulefforts.com

46 Blakemore, S (2000). POST Report 140, Early Years Learning. London. Available online: www.parliament.uk/post/pn140.pdf

47 Resnick, M and Silverman, B. Some reflections on designing construction kits for kids. In Proceedings of ACM IDC05: Interaction Design and Children, 117-122

48 Macaulay, D (1990). Black and White. Boston: Houghton Mifflin

49 Hornecker, E (2007). Learning about interactivity from physical toys. Paper presented at Nordic Design Research Conference, Stockholm

50 Siraj-Blatchford, J and Whitebread, D (2003). Supporting ICT in the Early Years. Maidenhead: Open University Press

51 Ginsburg, HP and Golbeck, SL (2004). Thoughts on the future of research on mathematics and science learning and education. Early Childhood Research Quarterly, 19(1): 190-200

52 Resnick, M, Martin, F, Berg, R, Borovoy, R, Colella, V, Kramer, K and Silverman, B (1998). Digital manipulatives: new toys to think with. In M Atwood, C-M Karat, A Lund, J Coutaz and J Karat (eds) Proceedings of the Conference on Human Factors in Computing Systems (CHI). New York City: ACM Press

53 Eisenberg, M and DiBiase, J (1996). Mathematical manipulatives as designed artifacts: the cognitive, affective, and technological dimensions. In Proceedings of the 1996 International Conference on Learning Sciences. Evanston, Ill: ICLS

54 O'Malley, C and Stanton Fraser, D (2000). Literature Review in Learning with Tangible Technologies. Bristol: Futurelab

55 Marshall, P (2007). Do tangible interfaces enhance learning? In Proceedings of the 1st International Conference on Tangible and Embedded Interaction. Louisiana: ACM Press

56 Antle, AN (2007). The CTI framework: informing the design of tangible systems for children. In Proceedings of the 1st International Conference on Tangible and Embedded Interaction. Louisiana: ACM Press

57 Resnick, L (1992). From protoquantities to operators: building mathematical competence on a foundation of everyday knowledge. In G Leinhardt, R Putnam and A Hattrup (eds) Analyses of Arithmetic for Mathematics Teaching. Hillsdale, NJ: Erlbaum

58 Baroody, AJ (2006). Why children have difficulties mastering the basic number combinations and how to help them. Teaching Children Mathematics, 13(1): 22

59 Baroody, A, Lai, M and Mix, K (2006). The development of young children's early number and operation sense and its implication for early childhood education. In B Spodek and O Saracho (eds) Handbook of Research on the Education of Young Children. London: Lawrence Erlbaum Associates

60 Fuson, KC (1990). Conceptual structures for multiunit numbers: implications for learning and teaching multidigit addition, subtraction, and place value. Cognition and Instruction, 7(4): 343-403

61 Jones, GA, Thornton, CA, Putt, IJ, Hill, KM, Mogill, AT, Rich, BS and Van Zoest, LR (1996). Multidigit number sense: a framework for instruction and assessment. Journal for Research in Mathematics Education, 27(3): 310-336

62 Fröbel, F (1826). On the Education of Man (Die Menschenerziehung). Keilhau/Leipzig: Wienbrach

63 Montessori, M (1912). The Montessori Method. New York: Frederick Stokes Co

64 Bruner, J (1966). Toward a Theory of Instruction. Cambridge, MA: Harvard University Press

65 Piaget, J (1965). The Child's Conception of Number. New York: Norton

66 Lackoff, G and Núñez, R (2000). Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being. New York: Basic Books

67 Gelman, R and Baillargeon, R (1983). A review of some Piagetian concepts. In J Flavell and E Markman (eds) Handbook of Child Psychology. 3: 167-230

68 Edwards, L (2005). Metaphors and gestures in fraction talk. In 4th Congress of the European Society for Research in Mathematics Education. Sant Feliu de Guixols, Spain

69 Sowell, EJ (1989). Effects of manipulative materials in mathematics instruction. Journal for Research in Mathematics Education, 20(5): 498-505

70 Ball, D (1992). Magical hopes: manipulatives and the reform of math education. American Educator

71 Fuson, KC and Briars, DJ (1990). Using a base-10 blocks learning/teaching approach for 1st-grade and 2nd-grade place-value and multidigit addition and subtraction. Journal for Research in Mathematics Education, 21(3): p180-206

72 Chao, SJ, Stigler, JW and Woodward, JA (2000). The effects of physical materials on kindergartners' learning of number concepts. Cognition and Instruction, 18(3): 285-316

73 Clements, DH (1999). 'Concrete' manipulatives, concrete ideas. Contemporary Issues in Early Childhood, 1(1):45-60

74 Mix, KS. Spatial tools for mathematical thought. To appear in LB Smith, M Gasser and KS Mix (eds) Thinking Through Space. New York: Oxford University Press

75 Nunes, T and Bryant, P (1996). Children Doing Mathematics. Oxford: Blackwell Publishers

76 Martin, T and Schwartz, D (2005). Physically distributed learning: adapting and reinterpreting physical environments in the development of fraction concepts. Cognitive Science, 29(4): 587–625

77 Wearne, D and Hiebert, J (1988). A cognitive approach to meaningful mathematics instruction: testing a local theory using decimal numbers. Journal for Research in Mathematics Education, 19(5): 371-384

78 Moyer, P, Bolyard, J and Spikell, M (2002). What are virtual manipulatives? Teaching Children Mathematics, 8(6): 372-377

79 Wood, D, Wood, H, Ainsworth, S and O'Malley, C (1995). On becoming a tutor: toward an ontogenetic model. Cognition and Instruction, 13(4): 565-581

80 Clements, DH and S McMillen (1996). Rethinking 'concrete' manipulatives. Teaching Children Mathematics, 2(5): 270-279

81 Triona, LM and Klahr, D (2003). Point and click or grab and heft: comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. Cognition & Instruction, 21(2): 149-173

82 Alibali, MW and DiRusso, AA (1999). The function of gesture in learning to count: more than keeping track. Cognitive Development, 14(1): 37-56

83 Roth, WM (2002). From action to discourse: the bridging function of gestures. Cognitive Systems Research, 3(3): 535-554

84 Wilson, M (2001). The case for sensorimotor coding in working memory. Psychonomic Bulletin & Review, 8(1):44-57

85 Goldin-Meadow, S (2000). Beyond words: the importance of gesture to researchers and learners. Child Development, 71(1): 231-239

86 Iverson, JM and Goldin-Meadow, S (1997). What's communication got to do with it? Gesture in children blind from birth. Developmental Psychology, 33(3): 453-467

87 Sabena, C (2004). The role of gesture in conceptualisation: an exploratory study on the integral function. In 28th Conference of the International Group for the Psychology of Mathematics Education

88 Ehrlich, SB, Levine, SC and Goldin-Meadow, S (2006). The importance of gesture in children's spatial reasoning. Developmental Psychology, 42(6): 1259-1268

89 Goldin-Meadow, S, Nusbaum, H, Kelly, SD and Wagner, S (2001). Explaining math: gesturing lightens the load. Psychological Science, 12(6), 516-522

90 Goldin-Meadow, S. A helping hand in assessing children's knowledge: instructing adults to attend to gesture. Cognition and Instruction, 20(1), 1-26

91 Valenzeno, L, Alibali, MW and Klatzky, R (2003). Teachers' gestures facilitate students' learning: a lesson in symmetry. Contemporary Educational Psychology, 28(2): 187-204

92 Nunez, R (2004). Embodied cognition and the nature of mathematics: language, gesture, and abstraction. In K Forbus, D Gentner and T Regier (eds) Proceedings of the 26th Annual Conference of the Cognitive Science Society. Mahwah, NJ: Lawrence Erlbaum Associates

93 Mandler, G and Shebo, BJ (1982). Subitizing: an analysis of its component processes. Journal of Experimental Psychology (General), 111(1): 1-22

94 Dehaene, S (1992). Varieties of numerical abilities. Cognition, 44: 1-42

95 Greeno, JG (1991). Number sense as situated knowing in a conceptual domain. Journal for Research in Mathematics Education, 22(3): 170-218

96 Miller, KF and Stigler, JW (1991). Meanings of skill: effects of abacus expertise on number representation. Cognition & Instruction, 8(1): 29-67

97 Klein, AS, Beishuizen, M and Treffers, A (1998). The empty number line in Dutch second grades: realistic versus gradual program design. Journal for Research in Mathematics Education, 29(4): 443-464

98 Kaminski, JA, Sloutsky, VM and Heckler, AF (2006). Effects of concreteness on representation: an explanation for differential transfer. In R Sun and N Miyake (eds) Proceedings of the XXVIII Annual Conference of the Cognitive Science Society. Mahwah, NG: Erlbaum

99 Uttal, DH, Scudder, KV and DeLoache, JS (1997). Manipulatives as symbols: a new perspective on the use of concrete objects to teach mathematics. Journal of Applied Developmental Psychology, 18(1), 37-54

100 Zuckerman, O, Arida, S and Resnick, M (2005). Extending tangible interfaces for education: digital Montessori-inspired manipulatives. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Portland, Oregon: ACM Press

101 Khandelwal, M and Mazalek, A (2007). Teaching Table: a tangible mentor for pre-K math education. In Proceedings of the 1st International Conference on Tangible and Embedded Interaction. Louisiana: ACM Press, pp191-194

102 Baroody, AJ (1990). How and when should place-value concepts and skills be taught. Journal for Research in Mathematics Education, 21(4): 281-286

103 Patten, J and Ishii, H (2000). A comparison of spatial organization strategies in graphical and tangible user interfaces. In Proceedings of DARE: Designing Augmented Reality Environments. Elsinore, Denmark: ACM Press

104 Girouard, A, Solovey, ET, Hirshfield, L, Ecott, S, Shaer, O and Jacob, RJK (2007). Smart Blocks: a tangible mathematical manipulative. In Proceedings of the 1st International Conference on Tangible and Embedded Interaction. Louisiana: ACM Press

105 O'Hara, K. P., & Payne, S. J. (1998). The effects of operator implementation cost on planfulness of problem solving and learning. Cognitive Psychology, 35(1): 34-70.

106 Fraser, K, Rodden, T and O'Malley C (2007). Trust, privacy and relationships in 'pervasiveeducation': families' views on homework and technologies. In Lecture Notes in Computer Science, no 4480, Springer Berlin/ Heidelberg pp180-197

107 Lane, H (2008). Let Me Tell You a Story… The Guardian, 15 March (lifeandhealth.guardian.co.uk/family/story/0,,2265583,00.html)

108 Rogers, Y, Hazlewood, W,, Blevis, E and Lim, Y (2004). Finger talk: collaborative decision-making using talk and fingertip interaction around a tabletop display. In Proceedings of CHI'2004, ACM, 1271-1274

109 Unsworth, L (2003). Re-framing research and literacy relating to CD ROM narratives: addressing 'radical change' in digital age literature for children. Issues in Educational Research, 13(2):55-70

110 See for example Sutherland R, Robertson S and John P (2008). Improving Learning with ICT. Routledge

111 Plowman, L and Stephen, C (2005). Children, play and computers in pre-school education. British Journal of Educational Technology 36 (2) 145-158

112 For a discussion of the educational philosophy behind Logo see Papert S (1980), Basic Books

113 www.rm.com/sectorredirect.asp?cref=SRED95396&SrcURL=/successmaker

115 Plowman, L (2004). "Hey, hey, hey! It's time to play." Exploring and mapping children's interactions with 'smart' toys. In J Goldstein, D Buckingham and G Brougeres (eds) Toys, Games and Media, pp207-223. Lawrence Erlbaum, Mahwah , NJ

116 Futurelab has produced guidance on developing links between educational researchers and designers of interactive products, including how to access or commission relevant research. 'Educational research and the design of interactive media: building collaboration between designers and researchers' can be downloaded from www.futurelab.org.uk/resources/publications_reports_articles/handbooks/Handbook197

About Futurelab

Futurelab is passionate about transforming the way people learn. Tapping into the huge potential offered by digital and other technologies, we are developing innovative learning resources and practices that support new approaches to education for the 21st century.

Working in partnership with industry, policy and practice, Futurelab:

- incubates new ideas, taking them from the lab to the classroom
- offers hard evidence and practical advice to support the design and use of innovative learning tools
- communicates the latest thinking and practice in educational ICT
- provides the space for experimentation and the exchange of ideas between the creative, technology and education sectors.

A not-for-profit organisation, Futurelab is committed to sharing the lessons learnt from our research and development in order to inform positive change to educational policy and practice.

Futurelab
1 Canons Road
Harbourside
Bristol BS1 5UH
United Kingdom

tel: +44 (0)117 915 8200
fax: +44 (0)117 915 8201
e-mail: info@futurelab.org.uk
blog: flux.futurelab.org.uk
www.futurelab.org.uk

Registered charity 1113051

futurelab
innovation in education