

Limitless or pointless?: An Evaluation of Augmented Reality Technology in the School and Home

Rosemary Luckin
London Knowledge Lab,
Institute of Education, University of London,
23-29 Emerald Street, London WC1N 3QS, UK
E-mail: rose.luckin@gmail.com

Danaë Stanton Fraser
Department of Psychology,
University of Bath,
2 South, Bath BA2 7AY, UK
E-mail: D.StantonFraser@bath.ac.uk

Abstract: Augmented Reality technology appears to offer great potential to engage learners and to enhance the process of knowledge construction. However, very little work has undergone formal evaluation, resulting in a lack of a deep and systematic understanding of how AR can enhance learning. We report an extensive evaluation of an AR application developed by the BBC for young learners. This evaluation involved over 300 participants in their homes and school classrooms. Our findings support the claim that AR has the potential to promote learning and to motivate children to engage with learning activities. There is evidence that specific skills can be improved, that learners were motivated and challenged through the interactive problem solving activities and that the technology offered many opportunities for collaboration. Developers will however need a rich skill set in order to create applications that offer the necessary learner control, challenging interactivity and experience coherence.

Introduction and Background

In addition to the early applications of Augmented Reality (AR) to gaming, medical, and engineering applications, there have also been some interesting educational applications, that explore the potential of AR to bridge the learning gap between abstract descriptions and the real world phenomena to which they refer. Previous projects have encouraged children to learn about scientific processes in an 'ambient wood' (Rogers, Price, Randell, Stanton Fraser, Weal & Fitzpatrick, 2005) about predator behaviour in the 'savannah' (Facer, Joiner, Stanton, Reid, Hull & Kirk, 2004), and about natural disasters such as earthquakes through simulations within a classroom (Moher, Uphoff, Bhatt, Lopez Silva & Malcolm, 2008). The exploration of the physical environment has been a particular focus (see for example, Liarokapis, et al, 2006; Klopfer and Squire, 2008) and the potential of mobile and ubiquitous technologies has commanded attention (see for example, Sandor, and Klinker, 2007). These projects show the potential of AR to enhance the presentation of knowledge across a range of real-world settings and the creation of engaging ways of interacting with simulations: demonstrating the broad potential of this technology across a spectrum of learning activities.

However, important challenges must be addressed before this potential can be realized. While a host of AR prototypes have been developed, few have been

evaluated to any extent, and formal studies are rare: a recent review found that only 8% of work in this area had any formal evaluation and that most of these studies were performed in artificial or informal settings, with very few studies of collaboration (Dunser, Grasset & Billingham, 2008). We therefore currently lack a deep and systematic understanding of how AR can enhance learning, and how to design long-term deployments in which teachers and students can regularly use the technology without extensive hands-on support from researchers. In this paper we discuss an extensive evaluation of AR book technology with learners in school and at home. This work extends previous evaluations using earlier versions of this AR technology conducted with science learning in school (Kerawalla et al, 2006)

The Technology

Possibly the most typical view of AR is one of using see-through head-mounted displays and tracking and registration systems to dynamically register 3D graphics on a view of the everyday world, a variety of other AR interfaces are possible including handheld, table-top, stand-mounted and projected displays, as well as the use of other modalities such as audio. However, it is possible to offer an augmented experience using less expensive and more accessible technologies that can be downloaded from a website and used in conjunction with a standard webcam. These applications use a virtual mirror interface that is relatively inexpensive, highly portable and relatively quick and easy to set up. The AR experience is achieved through the integration of the ARToolkit software (see <http://www.hitl.washington.edu/artoolkit/>), virtual 3D content created using a virtual 3D modeling package, and a standard laptop or desktop computer fitted with a webcam (Hornecker & Dunser, 2009). A person holds a card with a 2D geometric shape mounted on a white background (referred to as a 'paddle') in view of the web camera, the ARToolkit software recognizes this in real time, and attaches the 3D image to the paddle. On the computer screen the person appears alongside the 3D digital image. The benefits of this AR virtual mirror interface are that users can interact with the 3D content via the interface without having to wear headsets. Learners can hold the 'paddles' and explore and identify the characteristics of components of the virtual 3D model by inspection of its content as well as by rotating the tile so that the image can be seen from different perspectives. Figure 1 illustrates this technology.

The studies reported here were completed in collaboration with the BBC and evaluated a BBC AR application consisting of three story telling applications. Two applications were in the form of a story book that could be printed out, the third was a pack of characters and story elements with which users could tell their own stories (see <http://www.guardian.co.uk/education/2006/mar/07/elearning.technology15>). The printed material contained the geometric shapes that needed to be cut out and attached to card in order to form the AR 'paddles' (as illustrated in the left-hand image of Figure 1). The book could be read along with talking book style software that could be downloaded and run on a laptop or desktop PC. The software prompted the user as to which of the selection of paddles available needed to be held in sight of the webcam in order to produce the appropriate 3D animation on screen. On occasions more than one paddle was required and the user needed to co-ordinate use of the paddles in order to produce an on-screen interaction between the 3D animations. For example in the first of the two story books: called Little Feet and Big Feet (LFBF) two paddles each resulted in an animation of breaking an egg. The virtual eggs needed to be cracked by moving the paddles together in order for

the two chick story characters to be hatched. Other interactions included 'Sneak Past the Fox' in which the paddles representing the chick characters had to be moved carefully past a third animation of a fox; and 'Pile the Stones' in which users had to correctly order 'paddles' each of which represented a stone of a different size in order to build a pile of stones so that the chicks could climb to freedom from the fox. The second storybook also had interactive elements that involved users in creating a virtual catapult and placing animal characters in the correct order to build an animal tower. The value added by AR for storytelling when compared to ordinary text and text plus pop-up illustration has been demonstrated by McKenzie and Darnell. (2003), who argued that AR enhances the experience in a number of ways, such as allowing **the reader to be actively engaged in object manipulation**. The books are no longer static sources of information.

Figure 1 – The AR technology in use: the 'paddles' (left) and the image on-screen (right)



Empirical Methodology

The research team conducted an evaluation of the BBC AR story software in classrooms and homes with learners ranging from 3 to 6 years of age over a 4-month period (a small group of older users up to age 16 years from special education schools also took part). A total of 304 participants registered their willingness to take part through the BBC website, they were therefore largely self-selecting. At the start of the trial a single story pack: Little Feet and Big Feet (LFBF) was available, in month two, a second story pack: Looking for the Sun (LFTS) was produced, followed in month three by a third story pack: Make a Story (MAS).

Table 1: Summary of Data Collection Methods.

	Story pack 1 (LFBF)	Story pack 2 (LFTS)	Story pack 3 (MAS)
Observations in Homes	11	7	4
Observations in Schools	210	101	0
Survey & Phone interviews	71 responses in total – all 3 packs available for later respondents		

Total users	304
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A variety of data sources were collected and are summarized in Table 1 and are detailed below:

1. An email survey was sent out approximately 6 weeks after participants registered. Of the 71 responses received, 22 were from parents, 40 from teachers and ICT co-ordinators, and 11 were from people in IT related occupations (2 people placed themselves in two categories).
2. Telephone interviews were conducted with fourteen users who expressed a willingness to take part in further research when they responded to the email survey. Of those interviewed, four were home users, seven were school users and three used the software both at school and at home.
3. Observations (video tapes and researcher notes) and interviews with ten schools and seven homes from a wide range of backgrounds in London and the South West of England.
4. Videotapes and researcher notes from a study involving 12 children comparing the use of the Looking for the sun story in the form of the AR storybook, a Flash software application and a paper based pop-up book. Data sources from this study also include post session interviews plus children's drawings.

This paper discusses the findings from this rich data set with a focus on interactivity, engagement and impact on learning. There is insufficient space here to provide a detailed discussion of all data sources and we therefore focus upon the telephone interviews and observations. We do however offer a brief summary of findings from the survey and comparative study and draw on all sources for the concluding discussions and recommendations.

Findings

The email survey consisted of fifteen questions with closed answer responses and the opportunity to add extra comments. The questions asked firstly for basic demographic information, how the participant had become aware of the AR technology and about any technical difficulties experienced. A second set of questions enquired about who had initiated the usage sessions and who had taken control. A third area of questioning was about enjoyment and what aspects of the experience had been most/least enjoyable. The final section of the questionnaire asked about the participant's envisaged future use and recommendations.

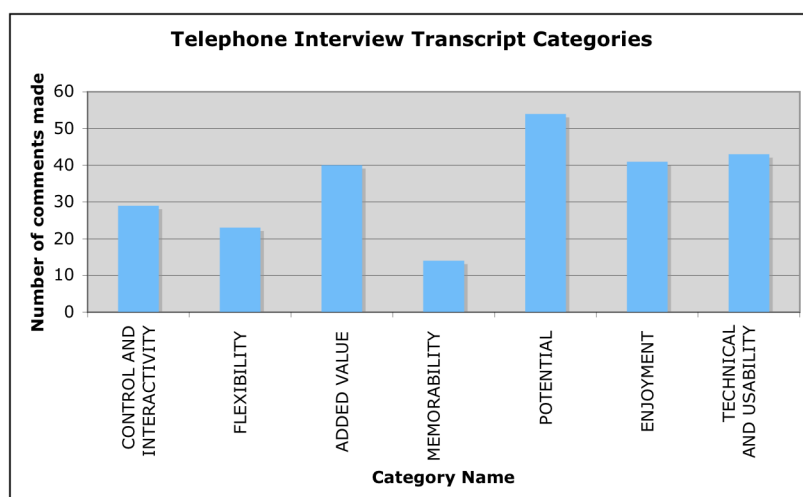
The results of our analysis of participant answers reveals that initiation of a story session mainly came from the adult, although 30% of those who responded said that sessions were initiated by both themselves and the learners with whom they were working. Control of the story once up and running was a more shared experience with only 25% of respondents reporting that they, the adult, maintained control of the speed of storytelling. Many comments related to children's engagement with the characters and the 3D scenes. 93% of those who answered reported some level of enjoyment of the screen characters and the book, whilst 98% of those who answered reported some level of enjoyment of playing with the screen characters only. The majority of users (62%) reported that children's favourite part of the experience was watching and playing with the animated characters on screen, particularly the fox.

Adult users also reported that it was the way in which the AR story packs enabled children to explore and control characters that was their favourite aspect of the experience, they also responded well to the 3D technology experience. Users certainly saw beyond the storybook with all respondents reporting that they had also used the characters either without the story (72%) or in other ways (28%).

The telephone interviews

Telephone interviews were conducted with fourteen users who expressed a willingness to take part further when they responded to the email survey. Respondents to the telephone interview were able to report on the use of the AR story packs with individuals and pairs in the home as well as small groups and classes at school. Their experience included use with learners with special needs whose age ranged from 3 to 16 years. All had used story packs 1 and 2; some had also tried story pack 3. Nine of the fourteen respondents had recommended the software to others who were now using it, and twelve planned to continue to use the story packs in the future.

Table T1 Telephone Interview Categories of talk



The telephone interviews were transcribed and then coded into the following themes: Control and Interactivity, Flexibility, Added Value, Memorability, Potential, Enjoyment and Technical/Usability. Table 2 illustrates the number of different comments made in each of the categories and indicates that the greatest variety of comments were made about the potential of the AR approach. In the section that follows each of the categories of comments are summarized into their representative issues.

Within the *control and interactivity* category comments fell into three main types:

- Discussion of the need for children to develop coordination skills to use the AR effectively;
- Concern with enjoyment: the way that children were able to interact with the characters and beyond the keyboard, and the potential the software gave parents to work with their children around the computer;

- Manipulation and vanishing AR images. Views about the way in which even young children were able to use the AR with a little practice were summed up in the comment:

“Well most of them really got the hang of manipulating them on the screen and stuff, and they soon learnt that you shouldn’t cover up all the shapes and stuff. It was just we found there were a couple bits where it was a little bit difficult to make two things manipulate, particularly when, with the egg one where you’ve got to make them crack, but you’ve got to keep them both in the camera view at the same time, so you can’t change the angle too much.”

Within the *flexibility* category comments fell into four main types:

- The potential offered by the technology for use with different age groups
- The potential for the technology to be applied to other curricular areas, for example “the syllabus mentions a scanner as an example, but I thought, ‘well a webcam’s a peripheral device’... they can help me focus it and put it in the right position and then I can use that with the story.”
- The versatility of the images for rotation so that users “can actually see all the way round the thing” and the variety of possible ways of using the software: “I’ve given the children the paddles and I’ve said just go ahead and see what you can do with it.... I found that you know using it as a stimulus for the children to lead the session has been the most powerful way to use it rather than an adult having control of it.”
- The mobility of the technology: “I can just put it on a laptop and then just carry it with a webcam. It’s not like a product we’ve had to buy in and worry about how to install it on the network.”

There were five different categories of comment about *added value*:

- The believe that AR offers a different kind of experience that ‘brings things to life’ by “being able to move the characters around – also getting the story read at the same time”
- That the experience was about more than just helping children to improve their reading: “the main thing we’ve been able to do really is then get them to tell the story, so not just basically linked to the book, but using the characters, but actually then developing their own story language.”
- The manner in which learners could be involved in manipulating the technology, particularly when they needed to solve a problem such as moving the paddles in such a way that they could build a pile of rocks for the chicks in the first story book: Involvement “they’re not just going ‘yeh push that button,’ they’re actually having to move things around. So they’re getting more into it, you know.”
- The additional information that was available through the combination of printed book, software and animation so that “much more information [was] visible than on a flat printed page.”
- The way in which the experience might help children with their reading. There were mixed views about this and these two responses offer different perspectives: 1) “As far as the reading goes I don’t know if it does actually benefit their reading because they’ll take the easy option and put the sound on or they’ll not bother, sometimes they just won’t even bother.” 2) “...the wee boy who

obviously wasn't coping with the way reading was being taught, maybe, you know he would benefit from exactly something, something other than the kind of conventional ways of teaching reading."

The *memorability* category was the smallest, with not all respondents believing that the experience could offer the possibility of increased memorability. The discussions fell into 3 main types of comment:

- That memory might be supported by the uniqueness of the experience: "I think it sticks in their minds a lot more, because it's not like any other software they've got, or any other stories they've got."
- The existence of the story as a factor that might help support memorability was also considered: "the fact that the pages were, you know, in front of them, in sequence, yes they could see that and so they, they would probably remember the story in a better order because of that as well."
- The possibility that the experience of the learner might support memorability, for example:

"Well probably things like the, you know, the bits where you had to feel, you know you felt like you were achieving something. You know, you were jumping through the hole or going round the fox, those sorts of things."

The *potential* offered by AR yielded the largest category for comments, with a range of issues being raised. These have been divided into three main types:

- Those that related to use by teachers: "The mind just could blow away, it's limitless". There were also a lot of comments about the potential range of uses to which AR could be put, with different subject areas being mentioned, including, Maths, Science, Drama, Design and technology, History and Road Safety.
- There were also comments that related to the use of AR with other technologies: "I was thinking maybe in the future, this type of technology might be used with the likes of mobile phones... with them having cameras on them nowadays"
- Suggestions for technical and content improvements to increase the potential of the technology, for example: " [at the moment] you are encouraging them to do, which is good, is to illustrate the story and write their own bits with it... but it would be good wouldn't it, if you had a video bit so that as you built the augmented reality story you could actually, because most laptops have a microphone, you could be speaking and you could make a video with the characters talking"

Within the *enjoyment* category comments reported excitement and fun by both adults and children. For example, one adult commented that: "I had quite a crowd of people around all really fascinated with the technology and asking me where I got it from", her colleagues were keen to know more about the technology. With respect to the children, there were also reflections of enjoyment, for example: "And the kids really like the fact that they've got like this little cartoon character who they can move around and stuff."

With respect to *technical and usability* issues, most participants were pleasantly surprised by how easy the technology was to use. The issues that were raised fell

into 4 main categories: those that related to the hardware, such as the compatibility of different webcams; those that referred to setting-up the technology, such as placement of the webcam; those that were about usability and the interface, such as the overlap of the control buttons of the interface and the animation viewing area; and those that were about specific story scenes where the interactions required were tricky to achieve with the paddles, for example.

Observations in the School and Home

Observations and interviews took place with ten schools and seven homes from a wide range of backgrounds. Sessions in schools were teacher-led with one member of the research team observing almost every session. Teachers started by using 'Little Feet and Big Feet' then progressed onto 'Looking for the Sun' depending on their response to the first story pack and the time they had available. Unfortunately, not all schools had the opportunity to use the third pack: 'Make-a-Story' due to the fact it was made available at the end of the summer term when teachers were restricted on time. Teachers were left to determine how they wanted to use the storybooks. Some teachers asked the children to read the text, whilst others read the story to the class and others simply pressed 'listen' so that they could listen to the story being narrated. The majority of teachers played the interactive scenes themselves, however some asked for volunteers to manipulate the paddles.

During school sessions, university staff made observational notes and recorded all feedback from teachers and children. All sessions were recorded on a video camera for future reference and later analysis. These transcripts were then categorized under the following five headings: Positive and Negative Engagement; Human Interactivity; Initiations (by children); Enhanced Learning, and Usability Issues.

Positive and Negative Engagement

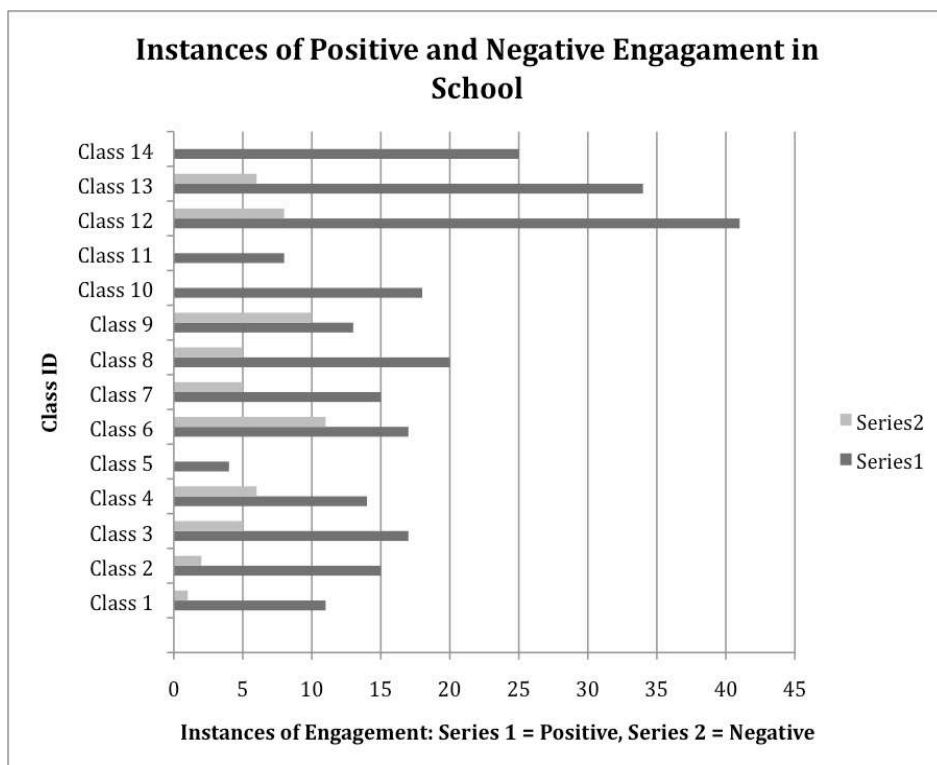
Positive engagement was deemed to have occurred when a child or children were obviously enjoying the experience and seem engaged with the storybook in a positive way. For example: the child saying, "This is fun"! and being more engaged in a physical way, such as kneeling up on a chair to be able to see the computer screen better, or through imitating the characters. Negative engagement was deemed to have occurred when a child or children were either being engaged in the story in a negative way or being disengaged from the story altogether. For example, expressing boredom when the teacher said, "we have lots of reading to do on this page" or asking if they could do something different, such as watch the television instead.

Analysis of the videos indicated that there was consistently more positive than negative engagement across all the sessions, Figure 2 below illustrates engagement in school class sessions. However, where a story was repeated, there was generally less positive and more negative engagement on the second run-through. The scene with most instances of positive engagement was 'Sneak Past the Fox' from the first storypack, 'Little Feet and Big Feet'. This was consistent across home and school use, although at home the 'Pile the Stones' scene came a close second. Fewer groups had used storypack 2: 'Looking for the sun', but for those groups that had used it, the 'Favourite Foods' scene provided the most positive engagement, followed by 'the catapult' scene.

Across each of the sessions there was no clear pattern of changes in positive and negative engagement other than a tendency for negative engagement levels to

remain constant or increase as the session ran: they never decreased. One surprising finding in this data was that levels of positive and negative engagement did not vary in accordance with whether the children or adult controlled the paddles. However, the levels of positive engagement were consistently high, so the opportunities for variance were restricted.

Figure 2 – Instances of Positive and Negative Engagement per school session



Human Interactivity

Examples of Interactivity were identified when the experience was made more interactive and the children were more involved in the story. For example, by the parent or teacher asking about the chick characters in the first story: “what can they do to get out of the shells”?

Findings here show that when the teacher or parent controls the session more, the level of child-to-child interactivity is reduced. This results in there being fewer instances of children interacting in class than in small groups where children control mouse and paddles. Within classroom situations increased child-to-child interactivity is only the result of the teacher encouraging it.

Whilst levels of child-to-child interactivity did vary between whole class and small group situations, levels of interactivity did not vary greatly between story packs. Likewise, levels of adult-to-child interactivity do not vary between the class and small group situations. However, certain scenes promoted increased interactivity. The ‘Crack the Eggs’ scene resulted in the greatest frequency of instances of interactivity, although the fact that this was the first scene must be born in mind, with increased interactivity arising largely from children being shown how to use the paddles. In total, there were less instances of human interactivity in the home

context. However, this was due to instances where children used the software alone at home. When a parent or another child was present levels of human interactivity were high.

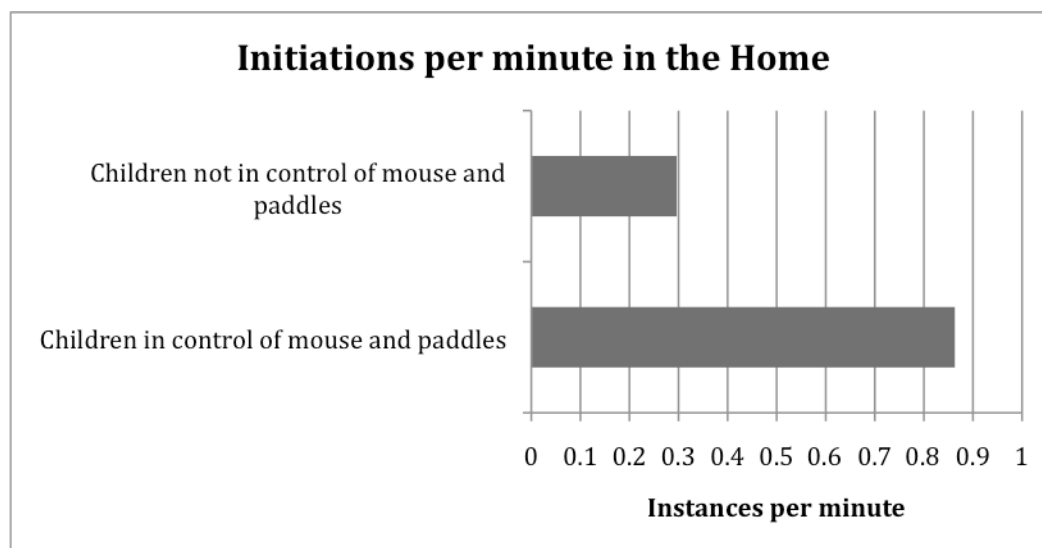
Initiations (by children)

Activity was identified as an initiation when children started anything related to the story, for example making suggestions of how the chicks could 'Sneak past the fox', or suggesting who was hiding in the tree trunk. The frequency of instances of initiations increased when:

- Children were in control of the paddles, the printed story pages or the mouse, as illustrated for the Home environment in Figure 3
- Children controlled the progression of the story. For example, they could elect to repeat scenes
- Children were asked questions by an adult
- Children were more familiar with the software or story, so that they knew when to press 'next', what to do with paddle and what happens in story.

There were no clear differences in levels of initiation between the three storypacks. However, there was a tendency for the 'Make a Story' pack to provide more initiations if the children were prompted to talk about what they were doing. There were no clear differences in the level of initiation between school and the home.

Figure 3 – Initiations by children in the Home environment



Enhanced Learning

Instances of enhanced learning were identified when there was evidence that the children were learning something more than the story as a result of using the application. For example, a discussion when using the Looking for the Sun storypack about what type of plant Dune Grass is, or what sort of crab the character called 'Claws' might be. In the classroom the teacher initiated all examples of enhanced learning, none were the result of children asking questions. More opportunities for enhanced learning were taken up in schools than at home.

Usability Issues

There were several examples of parents, teachers and children struggling with particular aspects of the technology, especially where it had an impact on the experience. For example, scenes not working well, characters visualizations being sensitive to light or camera angle, and the characters ‘sticking’ on pages. These findings are consistent with the data from the email and phone surveys.

Comparative Study of AR, Flash and Pop-up media: brief summary

Twelve children aged 5 – 6 years were divided into groups of four, with each of these groups having a mix of strong and weak readers. One group interacted with the AR version of the ‘Looking for the Sun’ story pack, the second interacted with the Flash version of the ‘Looking for the Sun’ story and the final group used 2 pop-up books of the story ‘Looking for the Sun’ created by the research team using the images from the Flash version of the story and the text from the AR story pack. All interactions took place in the children’s classroom and each group had a facilitator to guide them through their media and ensure each child had a chance to read the story and interact where possible. The children were allowed to interact with their media until they had completed the story, at which point they were asked to “draw pictures that would help another child who had not heard the story know what the story was about”. They were given a large sheet of paper divided into 4 drawing sections and headed: “Looking for the Sun. Draw parts you remember of the story in the spaces below”. Each child also took part in a brief interview during which they were asked what they could remember about the story. The session lasted 50 minutes. During this time the AR group interacted with the story pack for just over 15 minutes, before they started to draw, the group using the Flash story application interacted with it for over 30 minutes and the pop-up group used the books for approximately 10 minutes.

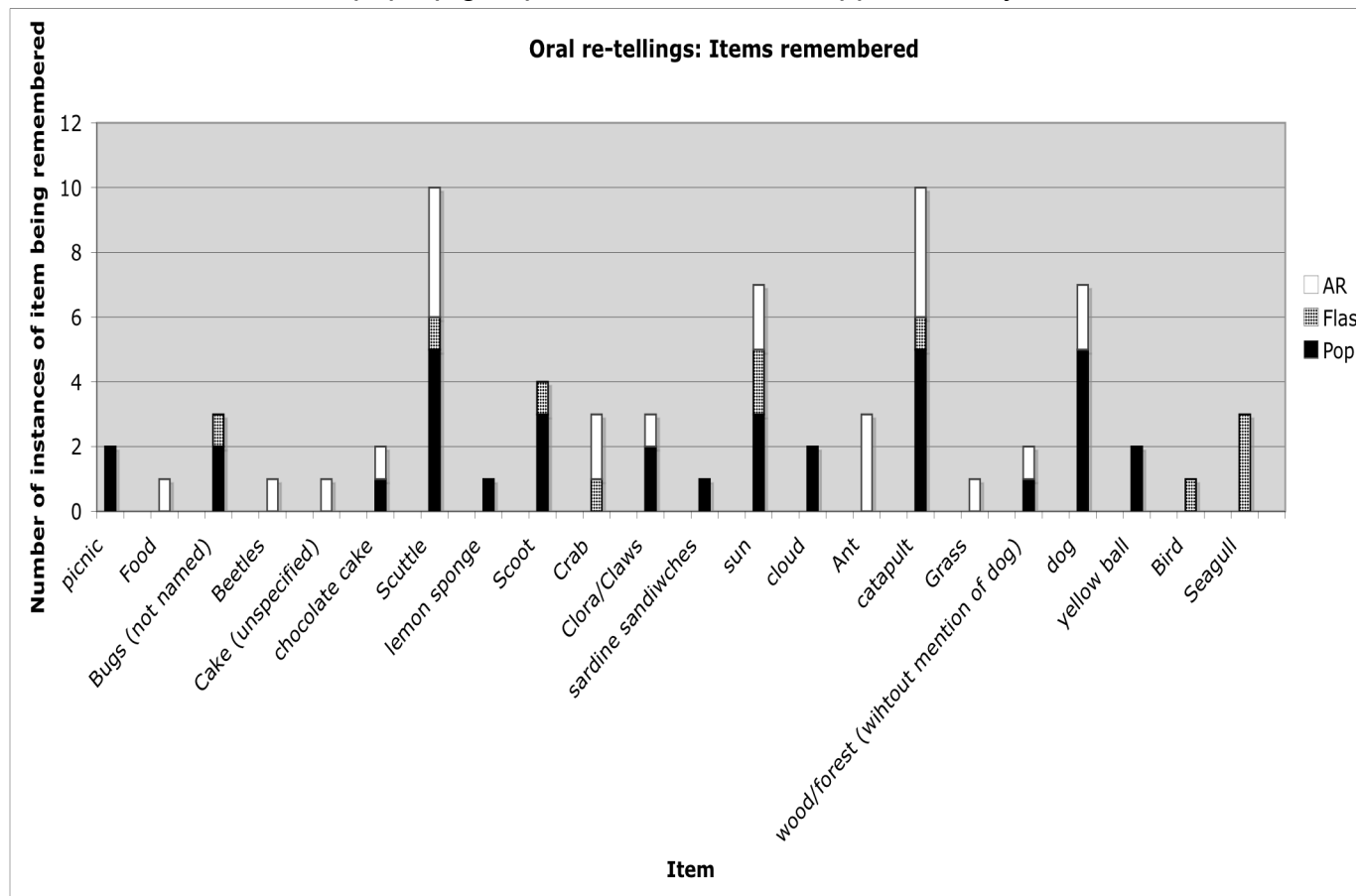


Figure 4 – Items remembered in children's oral re-tellings

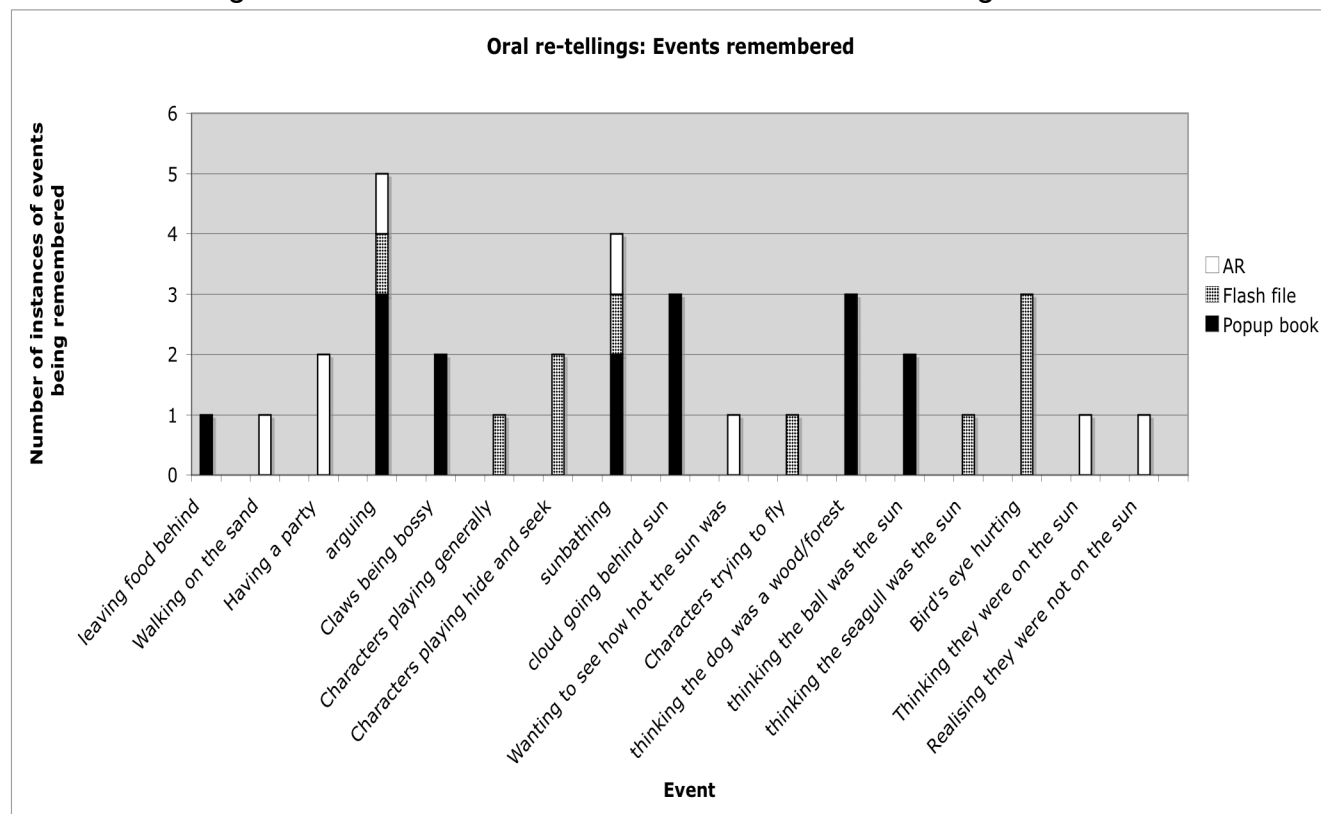


Figure 5 – Events remembered in children's oral re-tellings

In their interviews the children who interacted with the pop-up book remembered more items and events from the story than both the other groups, with the Flash group remembering the least. Figures 4 and 5 below illustrate what children from each group recalled at interview. These charts are organized along the horizontal axis from left to right in the order that the characters or events occurred in the story.

The children's drawings told a similar story, although there was a greater instance of the technology being regarded as important by the children in the AR group. Three of the four children in the AR group drew the technology in the form of a paddle.

The Impact of AR on Learning

Whilst the evaluation made no attempt to test children to explore their learning gains, it is possible to extract findings from the data that can increase our understanding of the way that the AR tools could promote learning. For example, we have identified issues within the data that are key to the process of learning, such as engagement and memorability. In addition to this, some teachers and parents expressed relevant opinions about potential learning uses.

Amongst the responses to the various questions in the email survey there are several indications that support the potential of the AR approach for promoting learning and motivating children to engage with learning activities. For example, there are comments about its potential to improve literacy, reading, speaking and listening; to improve ICT skills; to engage learners in storytelling and creation as well as reading; and about its potential for problem solving activities. Similarly, amongst the responses to the telephone survey there are further indications that support the

potential of the AR approach for promoting learning and motivating children to engage with learning activities. For example, there are comments about the skills that children may be able to develop beyond reading, such as speaking, listening and vocabulary enrichment and about the potential of AR to increase motivation.

Analysis of the observation videos indicated consistently more positive than negative engagement across all the sessions, with a particular emphasis upon those scenes with the strongest link between the story and the AR activity, such as the scene where the chicks need to sneak past the Fox. There are opportunities for human interactivity and collaboration when groups of learners use the AR storypacks, both at home and at school. Such human interaction is a key component of learning. There were also opportunities for children to initiate activities when they were in control of what happens, either through using the paddles and mouse, or through verbal suggestions. There was no clear difference in levels of initiation between the storypacks. However, there was a tendency for increased levels of initiation if the children were prompted to talk to about what they were doing. This was particularly noticeable in the data drawn from the third storypack. This suggests that future applications should consider what scaffolded support might be built into such 'free-play'.

Several instances of enhanced learning opportunities were identified in the observational data. This was more prevalent in schools than at home. This is not surprising with the school being a formal learning context where there is an expectation that children will be offered as many opportunities for learning as possible. Teachers are trained to provide learning opportunities, whilst parents are not. The fact that there were instances of parents providing enhanced learning opportunities at all suggests that some parents would like to be able to offer such opportunities at home, they may however feel less confident in their ability to do so.

The comparative study that explored the use of an AR, Flash and pop-up book version of 'Looking for the Sun' provides evidence about what children remember from their experiences. The pop-up book sessions promoted the best levels of recall, these sessions involved a good deal of collaboration between children. The AR approach certainly has the potential to promote and engender such collaborative and shared learning experiences and would benefit from a clearer structure to encourage such human interaction.

Discussion and Conclusion

The AR technology that we used with our participants was described as offering limitless opportunities: "The mind just could blow away", but are these opportunities that can support learning? There are many positive aspects of the AR software that can be built upon to increase the potential for learning. The nature of the content needs to ensure that **learners are offered challenging activities and problems to solve**; the captivating aspects of the software experience should be built upon to avoid the novelty of the technology wearing off and affecting user engagement. **There needs to be a stronger coupling between content and interactivity so that the links between the subject matter to be learnt and the interactive elements of the AR are strengthened.** For example, the activity of reading and following or creating the storyline is often separate from the interactive elements of the AR experience themselves. When the storyline is directly related to the interactivity the child is controlling through the paddles, for example when cracking the eggs to hatch the chick characters, the experience is both more engaging and memorable. Coherence between elements is important to ensure that the interactive elements don't interrupt

the temporal continuity of the story. For example the order in which characters are placed on top of each other in 'Looking for the Sun' alters the nature of what the character says. On occasions the dialogue makes no sense because it refers to a previous event that the child may not have experienced if he or she did not place a particular character in the tower in a particular order. There are also opportunities to build upon the enthusiasm and creativity of the users, both parents and teachers and support them in the production of their own resources, in terms of content, support and advice.

To support learning in the home and in the school, both parents and teachers need advice about how best to use AR and to help children learn through its use. The content and support materials need to be differentiated for school and home use in order to respect the differing needs of teachers and parents, whilst maintaining the opportunity for coherent multi location learning experiences. There is also considerable potential for further development of the collaborative aspects of the AR experience. User initiation was increased when children interacted with the software and with each other and/or the teacher or parent. The AR interface makes it easier for more than one user to be involved, for example through sharing the paddles. It has the potential to encourage social interaction and collaborative learning. The nature of the content and activities could be specifically designed to encourage this.

Users responded to having volition over their actions and more opportunities need to be found to build on this user control. However, achieving this is both subtle and complex and relies upon the correct balance between freedom and guidance. The balance varies across locations and user groups. For example, the more open-ended 'Make a Story' application required structuring by the adult in order for the children to make the most of the potential autonomy available to them. The nature of this structure would differ between home and school and between whole class and small group situations

On the negative side, there are barriers to adoption in the shape of technical and usability issues concerned with hardware, specific scene problems, set up time, web camera functionality and compatibility, issues with respect to lighting, the need to adapt classroom space and minor software usability and interface issues. The need for support material, particularly for teachers is also an issue that needs greater attention.

The emerging conclusion from this research with respect to the development of engaging AR applications is that developers will need a rich skill set in order to reap the potential described above.

Acknowledgments

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