Preprint. Eva Hornecker, Andreas Dünser. Of Pages and Paddles: Children's Expectations and Mistaken Interactions with Physical-Digital Tools. Interacting with Computers. Special issue on 'Physicality and Interaction'. Volume 21, Issues 1-2, January 2009, 95-107. Please refer to the printed version for citations and page numbers: http://dx.doi.org/10.1016/j.intcom.2008.10.007 copyright of the printed version Elsevier.

Of Pages and Paddles: Children's Expectations and Mistaken Interactions with Physical-Digital Tools

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ABSTRACT

An assumption behind new interface approaches that employ physical means of interaction is that these can leverage users' prior knowledge from the real world, making them intuitive or 'natural' to use. This paper presents a user study of tangible augmented reality, which shows that physical input tools can invite a wide variety of interaction behaviours and raise unmatched expectations about how to interact. Children played with interactive sequences in an augmented book using physical paddles to control the main characters. Our analysis focuses on how knowledge and skills that children have from the physical world succeed or fail to apply in the interaction with this application. We found that children expected the digital augmentations to behave and react analogous to physical 3D objects, encouraged by the ability to act in 3D space and the (digital) visual feedback. The affordances of the paddles as physical interaction devices invited actions that the system could not detect or interpret. In effect, children often struggled to understand what it was in their actions that made the system react.

Keywords

Physicality; tangible; Augmented Reality; affordance; augmented book; intuitive interaction; augmentation; physical-digital; hybrid tools;

1. MOTIVATION AND BACKGROUND

It is a wide held assumption that leveraging users' knowledge about the real world results in natural or intuitive interaction (Ishii and Ullmer, 1997; Ishii, 2007; Rauterberg et al, 1997). The terms most frequently associated with this assumption are 'real-world knowledge/skills', 'familiarity' and 'affordance'. Over the past 10 years, a variety of approaches for new interfaces have been introduced that attempt to "take advantage of users' well-entrenched skills and expectations about the real world" (Jacob et al, 2007). Many of these employ physical means of interaction, either tracking users' bodies or letting them move physical objects, the latter being an approach particularly associated with Augmented Reality (AR) and Tangible Interfaces.

Intuitive use of a product is generally understood to mean that it appears natural and obvious to the user how to use it, requiring only unconscious cognitive processing and relying on knowledge gained from prior experience (Blackler et al, 2003). Thus, for the design of intuitive AR interfaces, Billinghurst et al. (2005) propose to take "advantage of the immediacy and familiarity of everyday physical objects for effective manipulation of virtual content. (…) Using physical handles for virtual content enables people to use the skills they have developed throughout their lives to manipulate real objects." Often times, it is argued to "take advantage of natural physical affordances to achieve a heightened legibility and seamlessness of interaction" (Ishii and Ullmer, 1997), thereby supporting users in exploring and understanding a system by providing cues on how to interact with objects (cf. Laarni et al 2007; Zou et al, 2004; Jacob et al, 2007; Ishii, 2007).

The notion of affordances was introduced as a concept into HCI by Norman (1988) and denotes the possibilities for action that an object offers to somebody (Gibson, 1979). Norman (1999) emphasised the power of real (physical) affordances, whereas perceived affordances would only visually advertise the actual action possibilities (e.g., buttons in a GUI). Norman's chief examples include door handles and stoves, resonating with interface design approaches that favour reliance on physical input devices. Recently, he announced a trend for a return "to our roots" (Norman, 2007), with physical devices through which users control digital processes with body movement and mechanical manipulation.

Affordances are often described as something the designer can utilize and design into a system, providing the user with cues on how to interact with objects. However, similar to the use of metaphor in interfaces, which have a creative potential and may lead to unpredicted user interpretations that escape the control of the designer's intent (Blackwell, 2006), physical input devices have a potentially unlimited set of affordances (Schmidt and Wagner, 2002). Users perceive (McGrenere and Ho, 2000) and creatively select the affordances that suit their understanding of the system, their aims and the situation. For example, there is a multitude of variations in selecting one face of the seemingly simple shape of a cube. Sheridan and Kortuem (2006) systematically studied user manipulation of cubes of different size, shape and material. Wakkary and Hatala (2006) report on a field study of users interaction with a museum installation controlled by a cube worn on a wrist-lash. Both studies found users to employ diverse interaction techniques for selecting a cube's faces, with many combinations and variations of actions.

When integrated sensors enable devices to react to physical manipulation, designers can make use of the 'physical effects principle' (Fishkin et al, 2000), where system effects are analogous to the real-world effects of similar actions and adhere to naïve physics. For example, a handheld calendar can scroll to the next day if tilted. However, it is not always evident how such physical effects should work, or which objects they should act upon. For instance, Chatting (2008) found that users who were navigating a map by tilting a tablet PC are more successful with and prefer the interaction metaphor of 'the focus point rolling downhill like a marble' (tilting towards where you want to go) over that of the 'map as tablecloth' (that is, the map sliding down when the device is tilted). Whereas the map is visible and therefore lends itself to behaving like a physical object, the focus point on the map is only imaginary. This interaction metaphor of 'the focus point as a rolling marble' is not a straightforward translation from real-world behaviours. In this case, it is not evident for the designer *which* knowledge from prior experience in the real world (cf. Blackler et al 2003) users will access to make sense of their interactions with the digital device. For devices with complex functionality, such mappings would need to be developed for a rich set of digital actions and would need to be sufficiently consistent across different function spaces.

As sensors are getting cheaper and smaller, augmenting physical objects and enabling them to react to physical manipulation has become easier (e.g., Alonso et al, 2008; Chatting, 2008). It is therefore becoming increasingly important to study in detail how these devices are used and whether they achieve the aim of intuitive interaction.

This paper reports on a user study of augmented books. The aim was to investigate how young children (aged 6-7 years) would react to and interact with physical objects that are augmented with digital content. Specifically, children interact with tagged physical objects and see a live video image augmented with pictures and animations on a screen. The story's main characters are controlled via physical paddles that, when seen on-screen, carry the characters. The augmented books provide an example of interaction where digital behaviour is controlled through physical interaction and the users experience a hybrid of physical and digital behaviours.

In this paper, we re-analyse data from this study, examining in detail how children perceive and then choose how to interact with augmented physical objects. Our interest for this analysis was in how the children take advantage of object affordances that the system designers did not anticipate and what kind of knowledge from the real world they rely upon. In particular, our objective was to determine whether a novel interface design using physical input and visual augmentation was intuitive for them to use.

2. AN AUGMENTED BOOK STUDY

An early example of augmenting a physical medium with virtual content was the MagicBook, an augmented book (Billinghurst et al, 2001, 2005). Augmented books are an example of Tangible Augmented Reality, coupling an augmented visual display to a tangible physical interface that serves as the interaction means (Poupyrev et al, 2000; Billinghurst et al, 2005). A range of augmented books have been developed (McKenzie and Darnell, 2004; Woods et al, 2004; Saso et al, 2003; Zhou et al, 2004), but we still know little about the "how, what, and why" of augmented books (Shelton, 2002), their effectiveness, the instructional support needed and potential interaction issues or design criteria. This initially motivated our user study, conducted at the HitLabNZ, and the prior development of the AR books used in the study. In this article, we focus on whether the use of physical input devices enabled children to intuitively interact, rather than the educational benefits of augmented books or questions of story design (for these issues see Dünser and Hornecker, 2007b).

Figure 1. System set-up: Children playing an interactive sequence (sneaking around the fox, visible on-screen). The small image shows the on-screen view of a sequence with the chicks (on the paddles) in front of a tree trunk.

2.1. Background on the AR-Jam Study

Early research on augmented books focused on the utility of augmented reality for science education and on phenomena that benefit from interactive 3D visualisation. Another line of investigation is in the development of augmented books aimed at storytelling and as engaging means to explore stories. The BBC-Jam project was an online education service by the BBC (the UK's public service broadcaster), offering free interactive online learning services for 5 to 16 year olds.[1] As part of this project, one of the BBC's R&D groups was briefed to produce materials for primary literacy education that would use Augmented Reality technologies and could be distributed online. Amongst other projects, this resulted in the AR-Jam, a set of AR books made available for parents and children in the UK. These support activities and skills in the early stages of literacy, such as understanding of narrative and story telling (DfEE, 1998). These constitute the first steps towards children's ability to invent stories and are part of the learning objectives for year 1 (NC, 2007; DFES, 2008). The AR-Jam commissioners considered Augmented Reality to be especially suited for the literacy agenda for this age group, making stories more memorable.

[1] The remit of the BBC Jam was to offer a free interactive online learning service for 5 to 16 year olds, reflecting the school curricula in the UK. The service was rolled out incrementally and had been planned to run until 30 September 2008. It unfortunately had to be suspended with effect from 20 March 2007 due to complaints from the commercial sector about unfair competition interfering with trade in the EC. See http://www.bbc.co.uk/bbctrust/news/press_releases/14_03_2007.html. At this point, the AR-Jam already had about 1000 registered trial participants.

The HitLabNZ research team became involved as an outside party at this point after the AR-Jam was rolled out. Our aim was to develop a better understanding of design factors that influence user interaction with AR-books. The primary interest was to identify issues that might influence enjoyment and ease of interaction with augmented books, using the AR-Jam as a case study.

2.2. The AR-Jam books

To explain the full context of our study, we describe the AR-Jam books in detail and the design considerations and rationales of the BBC team.

At the time, the BBC had developed two augmented storybooks. The books employ a combination of physical pages and desktop interaction (screen, mouse), alternating traditional narrated text pages with interactive sequences. During interactive sequences, children interact with a scene of the story and control the story's main characters by moving physical paddles. This mix of narrated text and interactive sequences was motivated partly by budgetary restrictions (interactive sequences taking more time to develop), but was also requested by curriculum experts, wanting longer text passages to concur with curricula.

The BBC AR-Jam team had followed an iterative design approach, and tested early prototypes with children in the right age range (5-7) from local schools. Children were shown the Augmented Reality setup, let to play a while, and then asked to complete a specific task. These tests informed the interactive design, the use of audio, layout of on screen buttons, and use of text on screen. During production, further user testing was performed to discover the limitations of children's motor skills and conceptual understanding, resulting in simplification of interactive sequences.

2.2.1 The Two Stories

The first book was "Big Feet and Little Feet" and will be referred to as 'chick story' as shorthand. It tells the story of two little chicks, who are left outside the hen house at night, still being inside eggs. They have to hatch, try to find a place for the night to sleep, and need to overcome several obstacles, such as escaping a fox, and to find home again. The second book, “Looking for the Sun”, in brief referred to as ‘sun story’, involves four insects that attempt to get to the sun after having a picnic on the beach. They first inspect various foodstuffs they find on the beach. Then they try to climb to the sun by building a tower, and to catapult themselves up. With both books, the interactive sequences ask the children to help the main characters, each controlled by a dedicated paddle, achieve these things. The sun story was adapted from a children’s book by Rob Lewis and the chick story had been specifically written for the AR-Jam, with emphasis on appropriateness in terms of content, style and language for children up to age 7.

Figure 2. Page and paddles of chick story book.

2.2.2. Interaction with the Augmented Storybooks

The stories start with text pages shown on the computer screen (see figure 3 right). Text pages have navigation buttons for the next and the previous page, to skip to another section and to close the page. The children can choose to read the text or click on the ‘listen’ button to hear a recording. After each text section the page has to be closed to start the subsequent interactive sequence. In these sequences children see an augmented view on the monitor, which acts as an ‘augmented mirror’ (cf. Kerewalla et al, 2006). They interact with content on physical paper pages and paddles (figure 2), which becomes visible in this augmented mirror (see figure 1 and 3). The children have a third-person view of the scene, seeing the characters move on the screen.

The paddles serve as physical input devices, representing and controlling the main characters of the story, while the paper pages provide the setting for events or scenes within the story (which sometimes include further story characters such as the fox). The AR technology augments the physical pages and paddles with animated 3D content. Each interactive sequence is represented on a separate paper page, requiring readers to ‘open’ this page. Some sequences are organised as a series of pages. Figure 3 shows an on-screen view of the scene where the chicks have to sneak around a sleeping fox. After completing a sequence successfully, the readers can mouse-click on 'Play again' to repeat the sequence or can move on to the next text section. Each sequence requires the children to solve a task for the story to progress or to re-enact an event narrated earlier in the text. The children have to figure out how the story characters can achieve their current goal, such as climbing through a fence. In this regard the AR-Jam stories are related to adventure games, bringing these into real space and allowing for physical manipulation. It was the designers' intention for children to playfully explore the space of potential actions, without fear of doing something wrong.

Figure 3. Example for interactive screen (left) and text page (right).

The physical pages usually have 'hotspots', indicated by a grey outline. Placing paddles on a hotspot triggers a predefined event. The physical page in Figure 1 (small picture on the right) is augmented with a tree trunk. Placing a character on the hotspot next to the tree trunk lets it inspect a cavity in the tree. Figure 3 (left) shows a situation in the story where the chicks have to sneak past the fox (following footprints from the start to the finish sign) without waking him up. When they get too close, the fox starts moving and growling. Once both chicks have reached the finish line (a hot spot) they rejoice over the escape.

The augmentation is based on AR Toolkit markers (Billinghurst et al, 2001) depicted on the pages and paddles. Figure 2 shows a non-augmented view of the page with the tree trunk. In the video image, animated 3D images are superimposed on markers. The augmented book thus becomes visible on-screen when pages and paddles are in camera view. A web-cam positioned on top of the screen makes the technology available at very low cost, requiring only minimal and cheap extension of technology already in place in many homes and classrooms. This setup allows the user to see real and virtual content in a combined view in front of them as well as themselves interacting with the story.

The technology and the context of the AR-Jam impose some limitations. Since the image recognition for markers is not fully reliable in un-controlled light conditions the developers added on-screen buttons for navigation in case a page is not detected correctly. Furthermore paddles only function properly as input devices when facing the camera; markers need to be visible. Moreover, the AR-Toolkit functionality ensures that augmented objects move in a correct perspective view with the paddles, but is less well suited to extracting 3D positional information. While the paddles can be moved freely in 3D space, the implemented interaction reacts only to 2D-proximity of markers in the video image, neglecting distance to the camera.

Other design constraints result from the overall use context. Testing of early prototypes had informed the development team to simplify interactive sequences by limiting the number of markers per scene to accommodate children's conceptual understanding and motor skills. The BBC team also had to conceive of a way of distributing the augmented books to parents or teachers, so that the system was easy to setup and deploy. The AR-Jam books comprise a package of software and printouts for download. The printouts include a brief manual, the actual 'book pages' and paddle shapes with markers on them to be cut out. Several considerations governed the choice of paddles and paper pages for the interactive sequences. The familiar form of a book was intended to solve the question of how to step through the story. The designers furthermore wanted children to be able to pick up and move markers to manipulate a character. Paddles provide a handle and a plate that can hold the marker. Handles decrease the chance of fingers covering the markers. While cubes would be a viable option, these were considered less practical, flat shapes being easier to cut and build. An added advantage of paddles is that they impose a direction, being held almost like a frying pan. This ensures that users always see the characters from the front.

2.3. Study Design

Children from two local primary schools, ages 6 ½ to 7 (year 2), participated in the study at the Christchurch South Learning Centre (New Zealand). This is consistent with the age group the stories were written for and corresponds to key stage 1 (age 5-7) in the UK system (NC, 2007). At this stage of schooling children should be able to read at least parts of simple texts.

To investigate whether reading skills and attitudes would affect children's responses and behaviour we solicited avid readers as well as children who do not enjoy reading and have reading skills below their age norm. Teachers from the collaborating schools identified and enlisted these two groups of children for our study. We initially employed both stories to gain broader insight into relevant design issues. As it quickly became evident that the sun story was less rich for analysis and had a range of interaction problems as well as having a somewhat fragmented story line, we decided to have the remaining participants all experience the chick story.

Because we were interested in the diversity of interaction behaviour and responses to the books, we varied the reading situation by letting some children read in pairs (of similar ability level, avid readers or low reading skills) and others on their own. As the pair condition puts children in a naturally communicative situation, providing more access to their thoughts (cf. Als et al, 2005), we had the majority read in pairs. All in all, four pairs and three individual readers (11 children) read the sun story, and ten pairs and three individual readers (23 children) the chick story.

The procedure was as follows: supervised by the researchers, each individual child or pair read and interacted with one of the storybooks. Children sat at a table, with the computer display and the physical elements (pages and paddles) in front of them, and a mouse (for navigating the text pages) towards the right (as to be seen in figure 1). Adhering to teachers' advice on children's limited attention span at this age, they were only given one of the two books to read. Pairs were seated next to each other and given free choice in how to share and coordinate the interaction. Researchers helped the children initially in how to move from page to page. After the reading, each child was interviewed individually about their experience and opinions, using a half-structured interview guideline, and were asked to re-tell the story, and then probed for concrete details (how did the chicks get over the fence?).

Reading sessions and interviews were videotaped with prior consent of the legal caregivers and schools. The camera was sat in a corner, recording a view of the events (as seen in figure 1 and 4).

2.3.1 Initial Findings

A first stage of analysis focused on engagement with the stories and issues of interaction and story design that need consideration in creation of the new media of AR-books. This initial analysis followed an open-ended interaction analysis approach, iteratively evolving and collecting issues for further analysis from repeated viewing of the video tapes (Jordan and Henderson, 1995).

We found that after initial assistance during the first interactive sequence most children were able to interact with the books without help. Children were intrigued by the augmented characters and enjoyed the session. Recall in the interviews was found to be better for story events covered in interactive sequences than for those solely conveyed in text pages, measured in terms of the percentage of story elements mentioned in the retelling exercise. Reading skills did not influence children's interactions with the interactive sequences and their ability to navigate on-screen content much. The sun story engaged children less than the chick story, and failed to provide a memorable storyline for retelling, children being unable to summarize the story in a few sentences in the interview and recalling less story elements when probed.

A comparison of the time taken for interactive sequences (coded from videos) indicated that overall, children seem to benefit from working with a partner. Pairs took less time (Dünser and Hornecker, 2007b), and showed more signs of play and enjoyment, such as laughter and playacting. Longer duration of interactive sequences for pairs was related more frequently to repeating a sequence than to getting stuck or not knowing how to go on, whereas individual readers only rarely repeated a sequence. We frequently saw children in pairs imitating each other's actions, which could result in picking up a useful 'how to' behaviour or in variation of a behaviour. Pairs thus seemed to benefit from a greater variety of manipulations being tried. We furthermore uncovered a range of general story and interface design issues that should be taken into account in the creation of augmented storybooks (in particular regarding the mix of on-screen and paper interaction) (for details see Dünser and Hornecker, 2007a, 2007b).

2.3.2. Data Re-Analysis

Our initial analysis revealed that children often attempted interactions that the system did not detect or react to. This, in particular, involved moving the paddles for a simulated jump or bashing paddles against other objects to crack the eggs. To investigate this systematically, we re-analyzed the video data from all children for interactions that make use of the paddle's physical affordances and indicate expectations that the augmented objects behave just like real 3D objects in the physical world. Analysis focused on interactions and movements with the paddles that the system design did not accommodate for.

We created a category scheme based on our detailed notes of identified incidents. This scheme was successively refined (see Table 1) and then used for coding the data, resulting in an overview of distribution and variation of behaviours (see section 3.2). Furthermore, typical and particularly interesting incidents were selected for detailed transcription and further analysis.

3. EXPECTATIONS OF PHYSICAL-ANALOGUE BEHAVIOUR

Our findings show the children attempting a whole range of 3D-interactions, trying to make the digital characters act in 3D space, and exploiting the affordances of paddles to be moved in space. We here refer to interactions that assume the augmented paddles to behave like real objects in the physical world as 'physical-analogue behaviours' (this is our own phrasing).

The children's visible behaviour provides evidence of them expecting the augmented objects to behave analogous to physical objects and to obey the laws of the physical world. For example, some children tried to let their chick sit on top of a (virtual) tree trunk by holding their paddle high above the tree visible on-screen (figure 5). Others tried to jump over obstacles, moving the paddle in an arch over the obstacle visible on-screen (a meaningless motion in terms of the implemented interaction techniques). When aiming to drop an object from the paddle onto the ground, several children held their paddle at a slight angle and wiggled it as if trying to let the object slide down, hoping for gravity to help (figure 6). Further evidence can be found in children's talk, for example, when asking whether they could climb or jump over an obstacle.

Two factors seemed to contribute to the children's expectations of the augmented paddles to have physical-analogue behaviour. First, the physical input devices – paddles – have the physical, 'real' affordance (Norman, 1999) of allowing for manipulation in 3D space. Second, the augmented view on-screen reinforces the impression of interacting in 3D-space. This is because the underlying technology tracks the markers' size and orientation, and shows the digital objects (overlaid on-screen onto markers) in a corresponding perspective view. Yet for the effects of interaction, only the 2D position of markers in the 2D camera picture is interpreted, ignoring the paddles' orientation and height. And, while paddles can be moved in 3D space, the augmented objects disappear when markers are invisible to the camera.

Most of the observed behaviours occurred with the chick story. This is largely due to the fact that most of its interactive sequences inherently referred to spatial relations (bashing eggs *against each other*, sneaking *around* a sleeping fox, getting *over* or *through* the fence), and thus invited exploration of paddle movement, often in relation to other objects. The sun story sequences in comparison were rather static, focusing on putting paddles on markers in a specified order, and rarely involved movement of two paddles at once.

3.1. Types of Physical-Analogue Behaviours

In this section vignettes with detailed transcripts from the videos are presented and discussed, distinguishing four main types of physical-analogue behaviours.

3.1.1. Banging Objects to Crack Eggs

The opening of the chick story comprised an interactive sequence that had most children instantly refer to physical interactions with real objects. The story begins with the mother hen having forgotten to bring her eggs into the hen house at night. On the augmented screen, the children see eggs on their paddles. Bringing paddles closer to each other makes one chick say:

"Lets do it again" (intended as a clue that the eggs need to be banged against each other). The children came up with a number of ways of trying to crack the eggs (see figure 4) besides of the one action that the system recognizes (moving paddles side-by-side in the horizontal plane). For instance, many children tried banging the paddles (which on-screen had the eggs sitting on them) face-down into the table or head-to-head into each other (we term this a headbutt). Both interactions result in the markers being occluded.

Figure 4. Children banging paddles in various ways to crack the eggs.

In the following vignette, two boys playfully attempt to crack the eggs. They repeat this interactive sequence a couple of times, laughing and joking. Even though they are successful, this is quite by coincidence (the markers coming into proximity to each other) and they do not identify the 'correct' way (despite repeating it four times within 3 ½ minutes).

> *Ken and Tom have already cracked the eggs once and want to repeat the sequence. They start hitting the paddles against each other vertically in the air, markers facing each other (effectively invisible for the camera). On the screen this looks as if knocking the tops of the eggs against each other. Having tried this a few times, they bash the paddles onto the table face-down (markers invisible). Ken starts, and Tom imitates him almost immediately.*
>
> *After a while Tom takes both paddles and whacks one paddle, the marker facing downward, onto the other paddle. Thus the paddle on top occludes the other. The markers are only briefly visible during the motion. Somehow the eggs finally crack. Tom says: "Do it again" and Ken hits his paddle on the table. He then starts to smack his paddle against his own head, and Tom imitates him. They laugh loudly and exaggerate their movements. After a while, Ken hits his paddle with its edge onto the table.*

This short vignette shows a wide range of different actions one might use to crack real eggs. The children seem to identify the paddles as 'the eggs', treating them as the story characters even when there is no view of the eggs on-screen (this fulfils intentions of the AR-Jam creators). Quick movements and fun experiments were rather typical for this interactive sequence, and many children in their excitement forgot about the need for markers to be visible for the camera. Working through the story, the children usually became more aware of this need and tried to keep markers facing up towards the camera. Yet this requires conscious effort, as evidenced by the many instances throughout the sessions when markers were occluded (holding them in extreme angles or moving a paddle over another marker).

Quite often the eggs only cracked by chance. When replaying the sequence children often had not grasped what exactly it was that made them crack, repeating the motions they did earlier without success. The system designers wanted the children to playfully explore different options for cracking the eggs. In this regard the interactions observed show that this design goal was successfully achieved.

3.1.2. Jumping On and Over Things

Often children attempted to capitalise on 3D space in their interactions. They attempted to let the chicks sit on top of a tree trunk visible on-screen, to jump over a sleeping fox, or to let the chicks jump over a fence, moving the paddle in an arc on-screen over the fence (see figure 5). One child, on encountering the fence, asked her partner: "can I climb this?" With another pair this expectation became even more explicit:

> *Nicky puts her paddle on the hotspot and asks: "What do I do, jump over?" Her partner Jane moves her paddle 'over' the fence in an arc while looking at the screen. Nicky puts her paddle onto the hotspot again and asks: "What do I do?" Jane responds: "Jump over" and Nicky moves her paddle in an arc over the fence visible on-screen.*

The spoken question and instruction provide additional evidence of children's expectations to be able to interact in 3D, analogue to how they would in the natural world. Figure 5 (left) shows a boy in the 'single user' condition attempting to let a chick sit on the tree trunk, hovering with the paddle in the air, while staring at the screen. On-screen the chick is positioned above the tree trunk. This action does not trigger any events from the system – the children have to position the paddle on the hotspot next to the tree trunk, which makes the chicks inspect a hole in it.

Figure 5. Trying to sit on top of the tree trunk and attempting to 'jump over' the fox.

In these interactions, children focused entirely on what they saw on the screen. While receiving no system reaction to jumping over the fox or to standing on a tree trunk evoked neither positive nor negative reactions from the children, a lack of system feedback to jumping over the fence led to confusion. In the latter case the children expected to have successfully achieved their goal of escaping the fox by getting onto the other side of the fence (seeing the chicks move over the fence in the view on-screen). Yet they would still hear the chicks talk about the fence and the fox closing up on them, contradicting what they just saw.

3.1.3. Letting Objects Slide Down

The tendency to rely on a physical world analogy posed a hurdle for most children asked to let the insect characters in the sun story build a tower. The insects need to stand on each others' shoulders; the intended challenge being to find out the order and to sequentially place paddles on the hotspot (smaller animals on top of bigger ones). The children often struggled with putting the paddle on the 'hot spot' to make their character jump onto the ground or onto another insect. One pair repeatedly tried to make the insects slide or fall from the paddle, holding the paddle in a slanted angle and shaking it.

Figure 6. (left) Trying to let objects slide from the paddle by holding it slanted. (right) One girl grabs the other's hand, instructing her to "push him down" and demonstrating how to hold the paddle.

A few children that read the chick story exhibited a similar behaviour. In the fence sequence, the chicks have stones in their hands and need to pile them on the ground to climb through a hole in the fence. Trying to let the chicks drop the stones, some children held their paddle in a similarly slanted angle, as if hoping for gravity to help drop the stone (see figure 6). The following vignette is from the sun story (Claws, Ant, and Scuttle are the story characters). At the end, one girl verbalises her understanding of the interaction and demonstrates it to the other. This makes explicit the children's assumptions.

> *One insect is already on the ground and two girls now try to make another one stand on its shoulders. Clara takes the Claws paddle and holds it vertical, but visible for the camera (as if letting the insect slide down), explains "and then Ant", takes another paddle and holds it vertical again (as if sliding down), explaining: "then Scuttle". Figure 6 (left) shows this hand posture. Alice takes the paddle with Scuttle, but holds it upside down and sideways onto the hotspot. She then turns the paddle around, holding it vertically upright (as if trying to let Scuttle slide down). Clara takes the paddle from her, holding it in a similar angle, and starts to wiggle the paddle until the insect finally jumps onto the tower, the marker being detected. Alice does the same with the next paddle, holding it first upside down, then upright and wiggling it.*
>
> *They discuss in which order the animals have to be in the tower. Again, the tower tumbles. Clara takes the paddle with Claws, waves it around, but occludes the marker on the paper page with her paddle. Alice tells her to "push him down", and takes her hand, tilting hand and paddle so the paddle faces downward (see figure 6, right).*

Here, one child's behaviour is copied by her friend and vice versa, a pattern already seen with Ken and Tom. In this case, imitation results in iterating a behaviour that does not progress towards the goal of action. As discussed earlier, children overall seemed to benefit from working in pairs and could similarly imitate a useful 'how to' behaviour. The rather coincidental successes of the girls in the vignette above reinforce their belief of having found the best way to make the insects jump off the paddle. The sequence further shows general difficulties with the system, the markers being easily occluded, especially with excited children acting simultaneously.

3.1.4. Stacking Paddles to Build a Tower

In the sun story, the spatial order of the tower to be built needs to be translated into a sequential placement of paddles. This challenge requires abstraction. Several children attempted to stack the paddles, literally building a tower (figure 7). One child asked the researchers at the start of this interactive sequence "so do I put them all on a pile like that?" providing further evidence that building a tower was interpreted to refer to the paddles. A short vignette illustrates this:

> *Kathy takes the first paddle and aligns it with the marker on the paper. She keeps the paddle in place and puts the next paddle on top of it. The tower (of two insects) tumbles. Kathy explains to Lea: "Oh, you have to get them right on top of each other" and aligns the paddles. Then she puts the third paddle on top, and takes the fourth, Lea reaches over and neatly aligns the paddle tower.*

Figure 7. Building a tower from paddles.

3.2. Conceptual Analysis

The vignettes show vivid examples of physical-analogue behaviours. Table 1 categorises the dominant behaviours observed. Behaviours indicate expectations, or hypotheses about the system, such as 'exerting force on the eggs will crack them'. Variations of the behaviour indicate a variation of the hypotheses ('I can bang the eggs into each other', or: 'I can use another object to hit against'). The video data was coded according to this classification and the graphs in figures 8 to 10 give an overview of which children exhibited specific variations of a behaviour and how often. Rapidly iterated movement was neglected for coding, and a new occurrence was counted on clear onset of a movement or after a pause. Figure 11 shows how many different behavioural variations each child employed with the chick story.

Table 1. Behaviours and their variations.

The graphs demonstrate high variability, with some variations of behaviours carried out only by a few children and others by many. Children also differ in terms of how many types of behaviours and movements they perform and how often. Within some pairs, there was a large disparity. This was often due to one child being more physically active (dominating, or labour was split into paper and screen-based interaction), which results in the second child not operating the paddles much.

These behaviours have two characteristics. Firstly, in exploring manipulation with the paddles the children are cued by the physical affordances of the paddles: the movements and manipulations that the paddles allow and invite. The cause-effect relationships that underlie their expectations are naïve physics laws, such as gravity. Secondly, which expectations become overt is context-specific. Specific types of behaviours typically occur in specific interactive sequences.

The children interpret the affordances of the physical paddle in relation to the story situation they interact with (cf. Gaver, 1991; McGrenere and Ho, 2000). When children try to free the chicks out of the eggs, they hit the paddles to crack the eggs. For this sequence we observed a large variety of 'banging' actions, while in other sequences hitting of paddles occurred only rarely and more as a joke or last resort when running out of ideas. Jumping over another object only occurred when this object was introduced as an obstacle to be overcome. These context-dependent expectations about which actions might result in desired effect are in line with how the AR-book operates. The paddles partly change function according to context. Specific actions are interpreted differently according to the situation, that is the current interactive sequence (in terms of story logic and resulting effects). Nevertheless, as our analysis has shown, frequently there was a huge gap between what children expected to be possible actions and what the system would detect and react to.

We also observed that children sometimes did not attempt to achieve a goal by manipulating paddles, for example, when 'flying' the chick like a toy airplane. These actions, playing with the 3D view on-screen, had no effects in terms of the story logic. This concurs with the designers' intentions, as it was one of the aims of the AR-Jam to allow for free play and exploration.

3.2.1. Banging and Bashing

Banging relies on the expectation of force applied to the egg making it crack. As demonstrated earlier, there is a wide variety of ways to 'bash' eggs. Only a very specific subset of this action space results in cracking them. Different variations are (a) using your own body, (b) banging paddles into each other, and (c) banging paddles onto other objects such as the table. Figure 8.a to 8.c provide an overview of how often these variations occurred and which children used which movements.

Figure 8. Banging behaviours and their variations in the chick story. Graphs are clustered by pair, with separate bars per child (individual readers listed as 'single'). 'Together' indicates a variation where children each hold a paddle and act in unison. The most common behaviours involve using the fist, hitting the paddle on the table, and hitting them onto another. The graphs also illustrate that some variations were only performed by few children.

8.a. Occurrences of variations of banging paddles by using one's own body.

8.b. Occurrences of variations of banging paddles against each other.

8.c. Occurrences of variations of banging paddles by using another object.

For using one's own body to crack the eggs (figure 8.a), hitting the paddle with the fist was the most common variant, followed by hitting it against one's head and pinching it with the fingers. Variations of banging paddles against each other (figure 8.b) include: banging them with their faces into each other (referred to as head-butt); hitting one from above onto the other;

and hitting paddles with the edges of another. Some actions could be performed by a pair in a joint effort (coded as ‘together’). One child even used the handle of his paddle, exploiting its shape, to hit the other paddle. Only the act of knocking and gently sliding paddles against each other (making the edges touch each other) would result in the eggs cracking (excluded from coding). Variations of banging against other objects (figure 8.c) include letting a paddle fall down, and hitting it flat onto or sideways against the table. Hitting a paddle onto the table (face-up or down) was by far the most frequent action in the ‘cracking the eggs’ sequence.

A few children were very careful in interacting with the paddles and only moved them slowly. It often took a while for them to bring them close enough together for an effect. Yet as they moved slowly and took care to keep the paddles in camera view, the markers were usually reliably detected. These children then quickly grasped that it was the vicinity of paddles that made the eggs crack.

13 children, that is about half of all participants, hit their paddles, some using only one type of movement and others many variations. All of these did this more than 3 times. Banging tended to be iterated quickly – sometimes up to 15 times in rapid succession (coded as one instance).

3.2.2. 3D Behaviours

The children often attempted to employ 3D space to create a spatial relation between objects (see figure 9). Their behaviours indicated that they expected the height and 3D-movement of the paddles in relation to other objects to be meaningful in terms of story actions. The children here responded to the paddle’s physical form, which can be freely moved in 3D, similar to a toy plane, and to the on-screen 3D view that indicates 3D spatial relationships between objects. We distinguish jumping (over something) and the attempt to stand on top of another object as 3D actions. 13 children out of 23 attempted one of these.

Figure 9. 3D-Behaviours and their variations plus sliding behavior in the chick story.

In the sequence where the chicks have to sneak around a sleeping fox, two children tried to jump over the fox. Later the chicks face a fence they are to climb through. Eight children (in 5 pairs) 'jumped' by moving the paddle in an arc at least once, whilst looking at the screen where they could see the chick's movement. Three children imitated their partner's action. When this visibly failed to result in a successful escape, children reacted with confusion, and in several cases required assistance by the researchers to detect the stones that the chicks held in their hands. 9 children (all in the pair reading condition) attempted to jump. In contrast to hitting the paddles in order to crack the eggs, most children only attempted to jump once.

Eight children attempted to stand on top of the tree trunk that the chicks encounter. Children held the paddle suspended in mid-air above the marker (the tree trunk) and hovered in this position.

3.2.3. Sliding Behaviours – Waiting for Gravity

A few children seemed to expect objects to follow gravity and to slide down when holding the paddle in an angle or upside down (figure 9 and 10). Sliding combines a 3D movement/posture with expectations of naïve physics to take effect. Often the effect of holding a paddle in an exaggerated angle (for an extended time) was tried to enhance by shaking and jittering. Three children exhibited 'sliding' behaviour when trying to put down stones the chicks held in their hands. Furthermore, one of the four pairs reading the sun story repeatedly attempted to drop the insect characters by slanting, shaking and flipping paddles sideways, and tapping them upside-down.

Figure 10. Incidents of sliding insects off paddle and stacking/aligning the 'tower' of paddles in the sun story.

3.2.4. Stacking Behaviours

A different behaviour, interpreting the paddles rather literally, seemed to be triggered by the instruction in the sun story to have the insects 'build a tower' (see figure 9). Three children in pairs and all three individual readers attempted at least once to stack the paddles. Most children quickly realised that the 'tower' does not refer to the paddles themselves. Yet 'stacking' was an almost immediate response. Further evidence for the 'stacking' behaviour is provided by three children carefully aligning stacked paddles, and one child then moving the stack onto the hotspot.

3.3. Variability Across Stories and Children

Interaction behaviours differed a lot, with variation in children being playfully explorative or more goal-oriented and strategically-minded; in how pairs collaborated (from strict divisions of labour, through harmonious sharing, to domination of one over the other and fights for control); and in the amount of physical-analogue behaviours. We here concentrate on the latter, reflecting on the role of the former two in increasing or decreasing physical-analogue behaviours.

Figure 11. Number of variations of the three major behaviours per child (chick story).

About two-thirds of all children that read the chick story engaged in physical-analogue behaviours that the system design cannot register and/or react to. Overall in nine out of 13 sessions (10 pairs and 3 individual readers) such physical-analogue behaviours were attempted. Figure 11 illustrates that most children engaged in at least two different types.

3.3.1. Differences across stories

With the sun story there were considerably less instances of physical-analogue behaviours, even though the interaction tools were similar, the most evident example being the stacking of paddles. Our analysis revealed that the style of interactive sequences in this story tended to prime children towards strategic behaviour, focusing on getting things done correctly (Dünser and Hornecker, 2007b). Children were usually asked to re-enact a previously narrated story event. They were less playful and explorative than the children reading the chick story who were provided with a more abstract goal and had to find out how to help the chicks achieve this,. Furthermore, as mentioned earlier, sequences in the chick story more often referred to spatial relations between objects, inviting complex and 3D movement of paddles.

The sun story usually required placing one paddle after another onto a hot spot next to an object in the scene. When the storyline referred to spatial relations, such as building a tower, this had to be translated into a sequence of paddle placements. In addition, the first interactive sequence merely asked children to look at the insect characters. Bringing paddles close to each other then had the insects wave. In contrast, the first scene of the chick story asked children to 'crack the eggs', inviting movement (with dramatic effects) and driving the story forward. Sneaking around the fox asked for a complex movement (a half circle) with paddles and allowed for simultaneous interaction with both paddles. In these regards the chick story made more use of the opportunities provided by the AR-technology for spatial movement, whereas the sun story rewarded sequential use and careful placement of paddles. In turn, inherently spatial story situations, which invite users to build on their everyday experience of space, may raise further expectations about being able to interact in a meaningful way in 3D space and increase the likelihood of children trying to exploit the space-related affordances of the paddles.

3.3.2. Differences between children

Some children did not employ any or only few physical-analogue behaviours (three of the pairs and in total eight children, see figure 11). These children could be characterised as more strategic and analytic. Children with this style of behaviour thought about how to act and discussed their approach before moving paddles, aiming to 'do things correct at first try'. They tended to move slowly, watching their movement on the table and on-screen (visibly moving their head up and down), taking care to keep the paddles in camera view. Thus, markers were usually reliably detected and children could relate their actions to system reactions. Strategic behaviour seemed to be primed by the sun story, but also occurred with some children reading the chick story. These children were only rarely interested in repeating a sequence, even if told they could.

Children who can be characterized as playfully discovering things were very likely to repeat a sequence (typically at least twice) and usually had both of a pair have a go. Overall they showed more signs of being engrossed and enjoying themselves (such as: laughter, humourous comments, playacting). Playful behaviour in combination with the increased likelihood to repeat sequences resulted in a higher number of incidents of physical-analogue behaviours, as children were exploring possible movements, imitating each other's prior actions, and immediately putting into action new ideas. Children who banged paddles often tended to follow a trial-and-error approach, sometimes deliberately and playfully exploring different movements, and in other cases frantically repeating a movement that had seemed successful earlier. This 'more of the same' response resulted in even more occurrences.

There also seems to be an effect of whether children worked in a pair or read alone. Only pairs attempted to jump (8 children). Overall the three children that read the chick story on their own utilised less physical analogue behaviours than pairs. A factor might be that pairs not only play with the story, but also with each other. This resulted in prolonged exploration and more playful behaviour, along with laughter and playacting, such as mimicking a walking motion with the paddle. A further benefit of reading in pairs was that pairs took less time to figure out how to 'solve' interactive sequences than individual readers (cf. Dünser and Hornecker, 2007b).

3.4. An Unused Option: The Pages

The playful and varied use of the paddles had largely been intended and deemed desirable by the system designers, even though extent and variety of interactions exceeded expectations. Some children extensively explored the action space of the paddles and many held them high up to the camera, getting a close-up, or flew them like toy planes. In this regard it is striking that almost none of the study participants made use of another option anticipated by designers.

Figure 12. Children often held paddles up or imitated a ‘walking movement’ with them. On the right, one of the few incidents of explicit manipulation of pages (inspecting a tree trunk).

Not only are the paddles mobile, but the paper pages that ‘carry’ the scenery (or setting) for interactive sequences can also be moved around. With a fixed camera, keeping the page in place gives a static viewpoint onto the scenery. By moving the page around children could manipulate this view. However, the children did not exploit this option: intentional movement of the pages occurred only twice. One child moved the page for better access to a hotspot and another held the page up and turned it around to inspect the setting from close-by (figure 12). This observation (or rather failure of occurrence) implies that letting children explore the setting for hidden cues (as was originally planned by system designers) by moving the pages about would require considerable scaffolding. The affordance objectively exists, it is not hidden (Gaver, 1991), but nonetheless goes unnoticed.

One of the reasons for this might again be expectations. The previous sections illustrated that children tended to treat paddles ‘as-if’, manipulating them as they would the real thing (e.g., eggs). Children are used to traditional books, and books have a standard orientation; it is unusual to turn them around. Experience thus discourages moving pages about. Furthermore, we are used to moving our view of the environment by moving ourselves (first-person viewpoint). The AR-Jam set-up requires users to move the pages with the scenery, whereas in the real world it is physically impossible to move the ground and your environment. The affordance of the paper pages thus is *inconsistent* with children’s experience of how to interact with the everyday world. In addition, with the mirror-view setup, head movement does not affect the perspective. Instead, children have to think about the web-cam as a third, immobile object (in addition to scene and own viewpoint), a ‘camera in hand’ (Ware and Osborne, 1990) interaction style being impossible.

4. DISCUSSION

Overall our study showed that children enjoyed the augmented books and were intrigued; in the follow-up interviews, they asked how it works, referred to the books as 'magic' and compared them to games (this is somewhat to be expected because of the novelty of the interaction and children's desire to please adults). Children quickly understood the general model of interaction via moving the paddles. But this understanding was challenged when they assumed real-world physics to take effect on the augmented objects, and when their actions did not take the limited visibility of markers into account.

We have illustrated how physical-analogue behavioural expectations result in young children attempting interactions that are similar to interactions in the real world, but not catered for by the system design, and vice versa result in them not taking advantage of possible means of interactions anticipated by designers. In addition to the physical affordances of the input elements (paddles) inviting certain uses, we identified users' expectations about what could be done with augmented objects as an important factor, influenced by experiences from the real world and the situational context of the storyline. Scenes requiring the children to move paddles in relation to other objects (not merely placing them) or to draw a path with the paddles, along with prior occurrences of such scenes, seemed to increase the expectation to be able to interact in 3D space.

4.1. A Design Dilemma: Improving Intuitive Use or Playfulness?

First, we consider how the design of the AR-Jam books could be improved to support intuitive use, making it obvious how to interact. Some of the problems evident in the interactions are an artefact of the pragmatics of the AR-Jam project, in particular the requirement for easy download and quick assembly. The materials need to be printed and cut into shape. To ease assembly, paddles (cut from printouts) carry markers only on one side. Therefore augmented characters cannot be turned upside down. As noted, children often forgot that markers would disappear when turning paddles upside down or moving them at extreme angles away from the camera. In practice, to sustain heavy use, it is sensible to glue the paddle shapes onto cardboard which then can easily have a second copy glued to its back. Yet this would prevent the user from quickly ‘deactivating’ a paddle by turning it upside down, a handy alternative to shovelling it out of camera view.

Tracking paddles in any orientation (markers on all sides) and use of a see-through display would alleviate some of the observed problems of markers moving out of camera view. Yet these improvements would not cut to the core of the issue of physical-analogue expectations. It is not the movement of paddles that is difficult to understand, since these are continuously and seamlessly mapped to the movement of the virtual characters on-screen, but the *semantic effects of actions*. There is a mismatch between the real affordance of the paddles to be moved in 3D space, and the visual feedback which creates a perceived affordance (Norman, 1999) for the children, who see the augmented objects faithfully hanging onto the paddles in 3D space, and the actual system behaviour. This visual feedback in this respect does *not* provide misinformation (McGrenere and Ho, 2000). The issue at stake is the system’s semantic interpretation of what moving paddles means. The children can only mimic the action, but not the desired effect.

Norman (1988) introduced not only the notion of affordances, but also the use of physical constraints to guide interaction and disable ‘wrong’ actions: e.g., a flap over a set of buttons creates a visible barrier discouraging users from using these buttons. Potential solutions to guide the interaction with the AR-Jam books along a clear pathway and to discourage other actions could thus constrain movement of the paddles mechanically, for example to the plane, disallowing 3D actions. Yet this would destroy the playfulness of the interaction, and negatively interfere with children’s engagement. Children would not be able to ‘fly’ the chicks like a plane, to playfully hit the fox, or to mimic a walking motion (see figure 12). Most of these actions were not intended by children to lead toward a goal, but were part of play-acting, which the AR-Jam system designers want to encourage.

Another problem with restricting the action possibilities of the paddles is that these are to be used differently in different interactive sequences. Actions that the system interprets in one sequence have no effect in another. The paddles, albeit restricted to controlling the main characters, have features of a generic tool, changing function according to context. Yet as they always represent the same characters, they are specific. We thus deal with an interesting case where it is ambiguous whether the input tool is strong-specific or generic (Fitzmaurice, 1996). Swapping tools midway through the story does not provide a solution, as the paddles create continuity throughout the story and allow children to identify with the characters. It might also be possible to detect actions that do not 'solve' a situation, and to provide 'negative feedback'. As there is a 'correct' way to solve interactive sequences (putting stones in front of the fence to climb through a hole), the manual action of jumping over the fence could result in the chick jumping, but falling down instantly (off the paddle) and complaining 'ouch, that hurt – I can't jump that high'. Yet having two distinct realms of experiencing the action creates a new set of problems. If proprioception (the bodily sense of where your limbs are located in space relative to each other), real-world view of paddles, and on-screen view are out of synch, it can harm the feeling of directly controlling the characters. The chick would jump in place, while the paddle moves forward. This might create new stumbling blocks, interrupting the flow of the interaction.

Because of the need to learn a vocabulary of valid terms, this, in many respects, is similar to problems encountered with speech interfaces or gestural input. On top of this comes the 'optical illusion' of the animated characters moving on-screen as desired. While direct manipulation at first provides a feeling of 'direct control', it then fails to have the effect that the user believes to just having seen. The confusion evoked by this disobedience of the world might be more severe than when indirect interaction methods following a conversational model of interaction fail to work.

We find that most potential measures to ease interaction would not influence physical-analogue expectations or would change the character of the books, interfering with the playful approach observed with many children, or might even result in new design conflicts. Since the aim of the books was to provide playful means of engaging with stories, and to enhance the motivation to read, interfering with playfulness would be clearly counterproductive.

4.2. Physical Input and Intuitive Use

The diversity in actions found in our study, with some variations carried out only by few children, some children exhibiting many and others few, has consequences for the design of physical-digital systems. Even when conducting prior user testing, another child might invent a new behaviour or vary one. This makes it inherently difficult for system developers to anticipate user behaviour and cater for it. Our case study provides a good example of this problem, as the AR-Jam was the result of an iterative development effort involving repeated user testing of prototypes at different stages.

Similar to the effects of reading in pairs versus alone, reading in pairs resulting in more variations, a change of use context might result in new variations of behaviours. Moreover, the system may be unable to track many of these. Detection and interpretation of behaviours is additionally complicated if further objects (unpredictable with varying contexts) are utilised. Our study thus demonstrates the difficulties in anticipating potential user interactions with physical input tools/objects.

The paddles as physical input tools worked almost too well in terms of encouraging physical interaction, children assuming real-world physics to apply to the augmented objects seen on-screen. The system fails to concur with these expectations, resulting in initial frustration and steepening the learning curve. This is because the system in some aspects provides a direct mapping of paddles and augmentation, with the desired effects (e.g., cracking the eggs), and at other times does not interpret the action as intended. The problem lies at the level of semantic interpretation of what actions mean. Which laws of physics are valid in which situation?

We might conclude that interaction could be enriched by more explicitly exploiting physical-analogue behaviours, using them as interaction metaphors. Given that the system provides users with a 3D input tool, this three-dimensionality should be acknowledged to some extent. Some researchers have successfully developed interfaces based on the ‘physical effects principle’, where system effects are analogous to the real-world effect of similar actions (Fishkin et al, 2000). But a more cautionary lesson is also recommended. Fishkin (2004) discusses the physical effects principle as a type of metaphor, which can be by noun (similarity in form or appearance) and/or verb (similarity of the action). The children in our study are led to assume a very strong verb metaphor to be in place, albeit the designers have only implemented a noun (identity) and a weak verb metaphor (movement of the respective augmented object).

Our findings of rich and varied interactions with the seemingly simple physical form and affordances of a paddle confirm the observations by Sheridan and Kortuem (2006), Wakkary and Hatala (2006) of users’ interactions with cubes. The analysis provided here extends these by highlighting the role of the use context in affecting user’s expectations and interpretations, and by showing that users may persist in attempting to exploit object affordances despite of a lack of positive system response to these actions. It indicates the inherent difficulties in anticipating which physical properties users will find remarkable and react to, and how they will handle the system. They furthermore highlight aspects of the interface design that contribute to users’ expectations.

The study demonstrated that the suggestions from the paddles were very powerful. Some children for example, despite a persistent lack of positive feedback, repeatedly tried sliding objects off the paddles by slanting and wiggling them. Children frequently forgot to keep paddles and markers in camera view. This provides evidence of how powerful the paddle’s ‘real affordances’ are (Norman, 1999). Clearly, most children were not stopping to reflect, or to attempt doing things in slow motion. Those children that did, acted strategically and were focused on ‘doing things correctly’. Yet stopping to reflect means that the tool stops being invisible and ready-at-hand and becomes present-at-hand (Dourish, 2001, Chalmers, 2005), requiring conscious attention. Building on users’ pre-existing knowledge of and skills with the everyday, non-computer world thus only seems to work half-way for achieving intuitive interaction, if intuitiveness is equated with readiness-at-hand.

5. CONCLUSION

Our study has shown how children interacting with augmented books expected animated augmented objects (which they could move around by moving optically tagged paddles) to behave according to naïve physics, waiting e.g., for gravity to let something slide down or trying to jump over objects. They expected system effects to their actions to resemble real-world effects of similar actions. The physical input elements (paddles) encouraged physical interaction rather too well, causing children to attempt actions that the system could not detect or react to. The richness in variation of actions along with the perpetuation of behaviours indicate the difficulty to resist the paddle affordances. The actions that the paddles invited could not be interpreted by the system on the same semantic level as expected by users. Many variations had not been anticipated by the system designers. Analysis furthermore revealed how children's expectations were encouraged by the possibility to interact in 3D space and the visual feedback by 3D digital visualisations on-screen, and were influenced by the situational context.

Our study exposes an inherent difficulty in the notion of 'real-world interaction'. This difficulty lies in the challenge to match the physical affordances and the actions these invite with the actual capabilities of the digital system and with users' understanding of interaction. A very careful analysis is required to detect where and why reference to prior skills and expectations about the physical world may provide intuitive interaction and where not. The 3D movement affordances of the paddles support playful and explorative interaction. They increase the degrees of freedom, resulting in a larger action space where many action variations have no effect towards the aim of action. One option for system designers is thus to provide rich feedback to the full range of manual actions (see Rogers and Muller, 2006), instead of thinking solely in terms of state transition diagrams and discrete events. It is interesting to note that most of the ideas discussed here on how to improve 'ease of use' of the AR-books in our study would make interaction more explicit and predictable, interfering with playful exploration and contradicting their very purpose.

In sum, it is not always evident how users will perceive and interpret physical input opportunities and how they will associate these to previous real-world experiences. Utilising physicality in interaction design can leverage knowledge of the physical world, but it is not always clear *which* knowledge and how the transfer takes place. The richness of affordances of physical objects can allow for rich interactions and exploration, but can also raise expectations that the designers did not anticipate, or cannot fulfil, because this richness of interactions leads to high variability.

ACKNOWLEDGMENTS

The AR-Jam books were developed by Gavin Baily (Interactive developer) at http://www.zupastudio.com/, Chris Potter (Character design, graphics, 3D modelling and animation) at http://www.grassblades.com/; the producers were: Brendan Lancaster and Dr Adrian Woolard at the BBC.

The original user study was conducted while both authors were at the HitLabNZ, funded under the MagicBook grant (NERF UOCX0204). We thank Christchurch South Learning Center, Nina Whitfield, Thorrington School, Waltham School, and all participants for helping to run the study. The BBC-Jam team provided us access to the AR-Jam system. We thank Brendan Lancaster and Adrian Woolard for discussing results and providing us insight into the background of the project at a time when the project had formally finished. The meta-analysis presented here has been supported by a German DFG post-doc project grant (Ho 3901/1-1).

Paul Marshall and Johann Habakuk Israel gave the impulse to turn the original workshop position paper into a journal article, and Paul Marshall assisted with preparation of the graphs. Yvonne Rogers immensely supported the writing with detailed feedback on several drafts, helping to focus and sharpen. Finally, we thank our reviewers for their valuable comments and suggestions.

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Figure Captions

Figure 1. System set-up: Children playing an interactive sequence (sneaking around the fox, visible on-screen). The small image shows the on-screen view of a sequence with the chicks (on the paddles) in front of a tree trunk.

Figure 2. Page and paddles of chick story book.

Figure 3. Example for interactive screen (left) and text page (right).

Figure 4. Children banging paddles in various ways to crack the eggs.

Figure 5. Trying to sit on top of the tree trunk and attempting to 'jump over' the fox.

Figure 6. (left) Trying to let objects slide from the paddle by holding it slanted. (right) One girl grabs the other's hand, instructing her to "push him down" and demonstrating how to hold the paddle.

Figure 7. Building a tower from paddles.

8.a. Occurrences of variations of banging paddles by using one's own body.

8.b. Occurrences of variations of banging paddles against each other.

8.c. Occurrences of variations of banging paddles by using another object.

Figure 8. Banging behaviours and their variations in the chick story. Graphs are clustered by pair, with separate bars per child (individual readers listed as 'single'). 'Together' indicates a variation where children each hold a paddle and act in unison. The most common behaviours involve using the fist, hitting the paddle on the table, and hitting them onto another. The graphs also illustrate that some variations were only performed by few children.

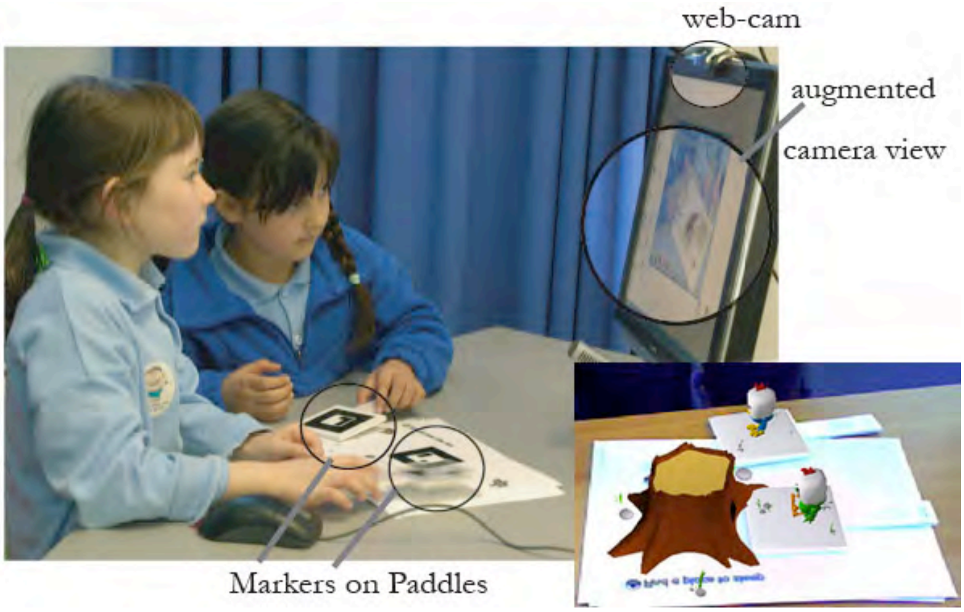
Figure 9. 3D-Behaviours and their variations plus sliding behavior in the chick story.

Figure 10. Incidents of sliding insects off paddle and stacking/aligning the 'tower' of paddles in the sun story.

Figure 11. Number of variations of the three major behaviours per child (chick story).

Figure 12. Children often held paddles up or imitated a 'walking movement' with them. On the right, one of the few incidents of explicit manipulation of pages (inspecting a tree trunk).

Figures



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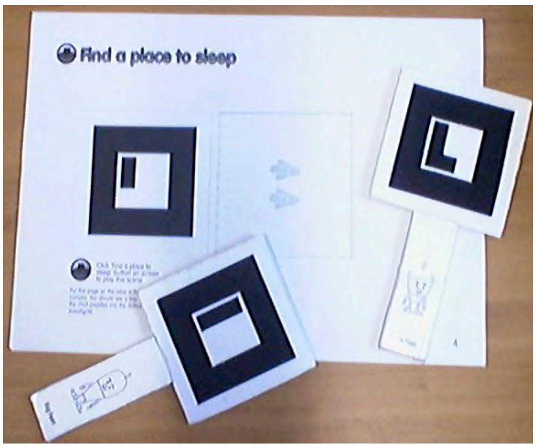

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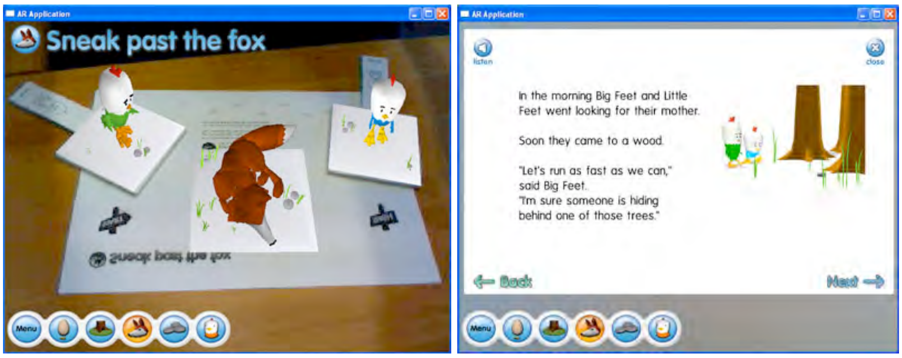

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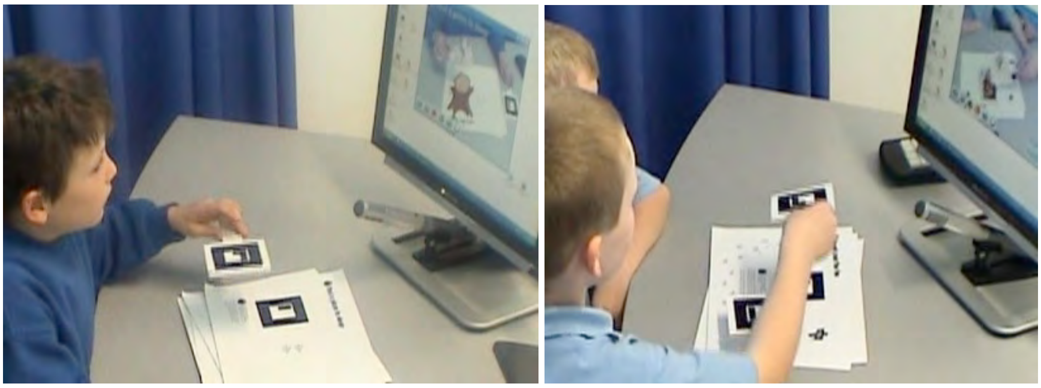
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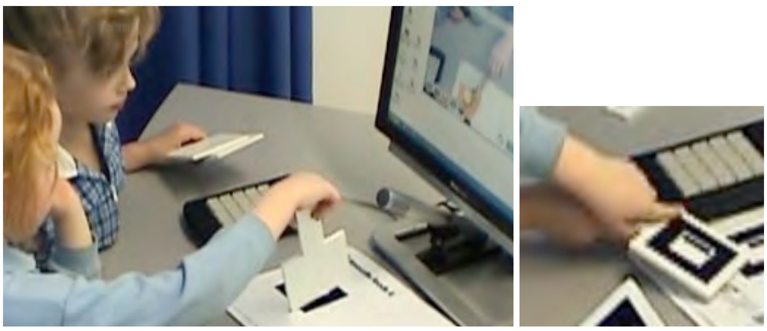

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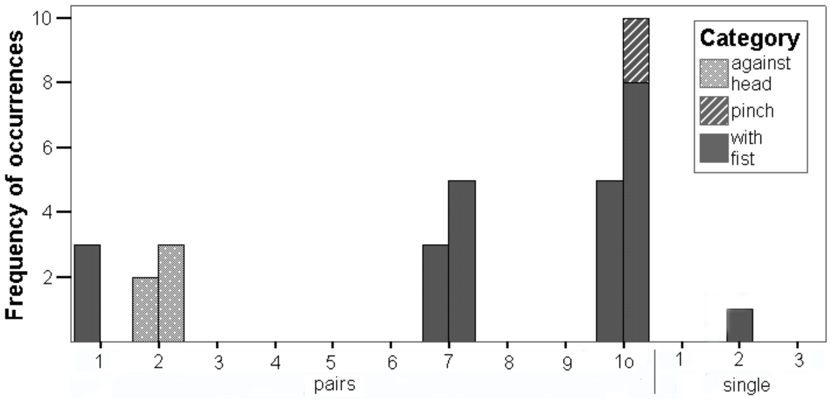

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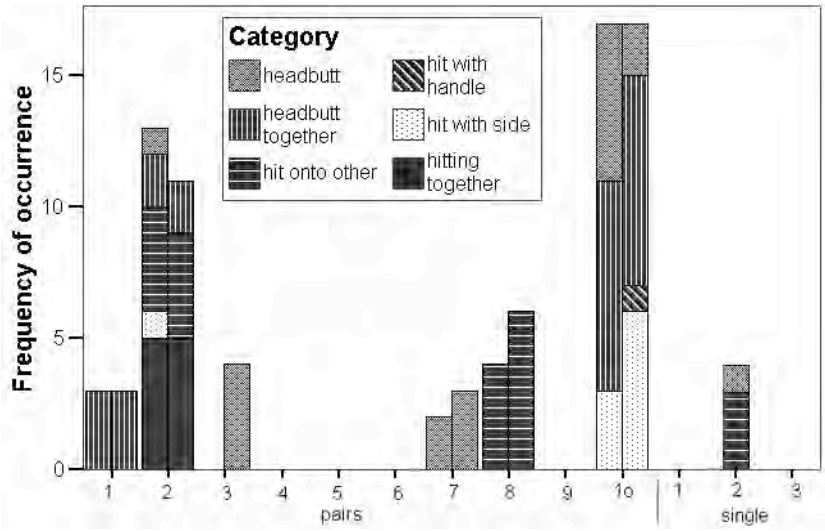

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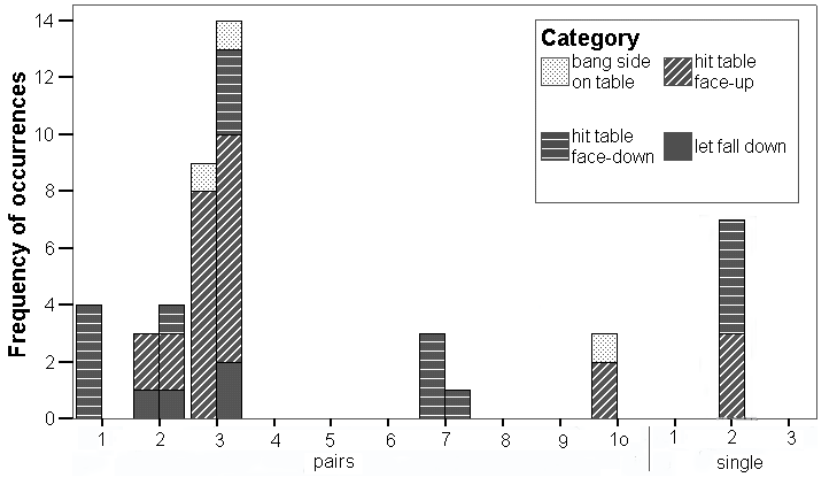

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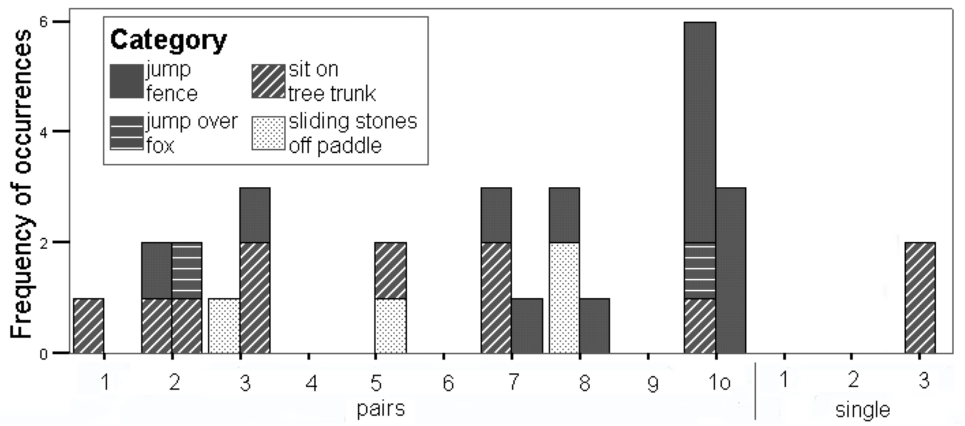

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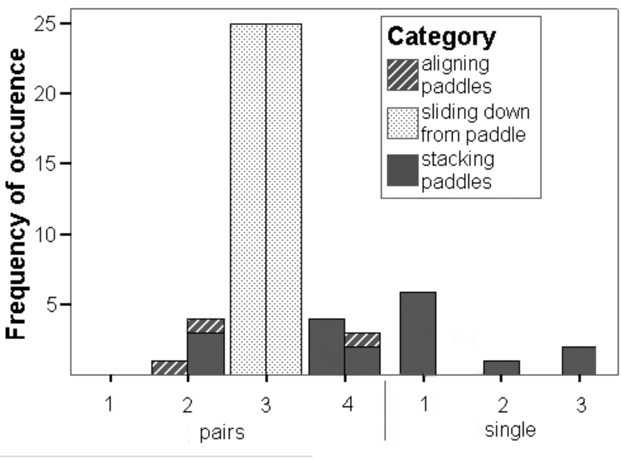

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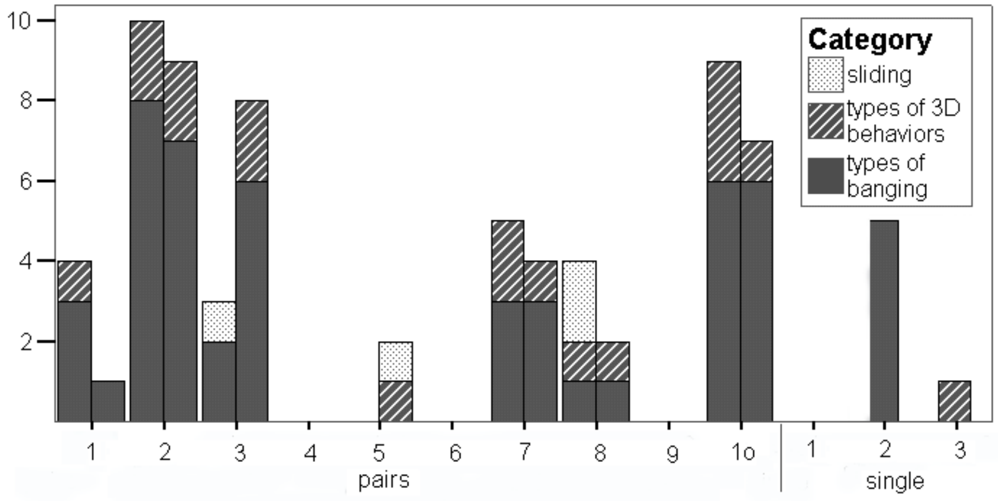

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Table Captions

Table 1. Behaviours and their variations.

Tables

Banging		
	Bash paddle with self (user's body)	
		With fist
		Against head
		Pinching
	Hit paddles against each other	
		Hit onto other paddle
		Hit with side
		Hit with handle
		'Headbutting' paddles into each other
		one of the above done by pair together
	Paddle with other object	
		Hit onto table face-up or face-down
		Let paddle fall on table
		Bang its side on table
3D Movement		
	Jumping over obstacles	
		Over the fox
		Over the fence
	Standing/Sitting on the tree trunk	
Sliding down		
	(intensified by shaking)	
Stacking		
	Stacking paddles to create tower	
	aligning paddles	

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