Physical Affordances Considered Harmful !?

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ABSTRACT

Frequently physical affordances are considered one of the main advantages of tangible interfaces or input devices, making interaction intuitive. This assumption may be overly simplistic – because physical objects have a multitude of physical affordances and properties, it is difficult for the designer to restrict these to (only) those that match with the digital system that they are connected with. This paper presents examples from a user study of children interacting with augmented books using physical paddles. These illustrate how children expected the digital augmentations to have physical 3D-behavior, encouraged by the possibility to interact in 3D space and by the (digital) visual feedback. The affordances of the physical interaction devices were rather deceiving, being a mismatch with the digital system's capabilities, and in effect intuitiveness of interaction broke down. Finally, a first cut at an analysis is presented of what our observations mean for the intuitiveness of tangible input elements and the use/virtue of physical affordances.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: Models and Principles, - *human factors*. H5.1 [**Information Interfaces**]: Multimedia Information Systems – *artificial, augmented and virtual realities.* H5.2 [**Information Interfaces**]: User Interfaces - *haptic I/O, input devices and strategies*.

General Terms

Design, Human Factors, Theory.

Keywords

Affordances, physicality, tangible, TUI, handles, augmented book, intuitive interaction, naturalness, augmentation.

1. INTRODUCTION

Frequently tangible user interfaces and physical computing in general are being argued for by alluding to their similarity with our experience from the physical world, being intuitive and allowing users to leverage their existing skills and experience [3, 4, 12, 13]. The physical affordances of tangibles are said to contribute to this intuitiveness. Observations from a prior project led me to regard the assumption that interaction guided by physical affordances of the natural world will transfer directly to the world of physical-digital ensembles as too simplistic. Physical affordances may on the contrary be misleading and deceiving, if physical representations are not closely mapped to the digital elements they are connected with – they may promise more than the system is able to do, and in effect increase the difficulties encountered.

The examples used here stem from a study with young children interacting with augmented books by manipulating physical paddles and paper sheets. The paddles in an on-screen view are super-imposed with animated characters from the book and serve to control their movements. This is very close to the notion of 'haptic direct manipulation' [10]. We found that children expected the augmented paddles to have physical 3D behaviors, expecting the 'physical effects principle' to apply [7], and employing what we referred to as 'physical metaphors' for their interactions [5]. Yet the system does not react (and cannot) as expected, and the children repeatedly struggled to achieve their aims. This obviously interferes with the 'augmented reading experience' which is the aim of the AR-book, system reactions being counterintuitive at times. The physical affordances here seem to be so strong in suggesting how to interact, that it is difficult for users to ignore them.

While our study involved children aged 6 to 7, this issue is likely to be of general relevance – adults may find it easier to disregard the affordances of physical input devices, to step back and analyze how the system reacts to their actions, but this would also mean that interaction is not intuitive (in the sense of being ready-at-hand [4]).

The final part of this position paper makes an attempt to shed more light on the underlying problem by discussing the paddles' role by applying several conceptual approaches to understanding affordances, intuitive interaction of tangibles, and direct manipulation. This analysis so far is not finished thinking yet, but points to the fuzzy role of the paddles, in-between being an interface, an interaction device, and a perceived interaction object...

2. CHILDREN READING AN AUGMENTED BOOK

The notion of an 'augmented book' [2, 3] inspires researchers and educators as a means to enhance books with interactive visualizations, animations, 3D graphics, and simulations, enhancing engagement and allowing for active manipulation and exploration of the content [17]. In terms of interaction technology, augmented books are midway between tangible interfaces and Augmented Reality, the interaction means being tangible and the view of the book augmented with digital images. There still is little known about the "how, what, and why" [17] of augmented books, their effectiveness, or the instructional support needed, and potential interaction issues or design criteria. This motivated the study done at the HitLab NZ which here serves as example.

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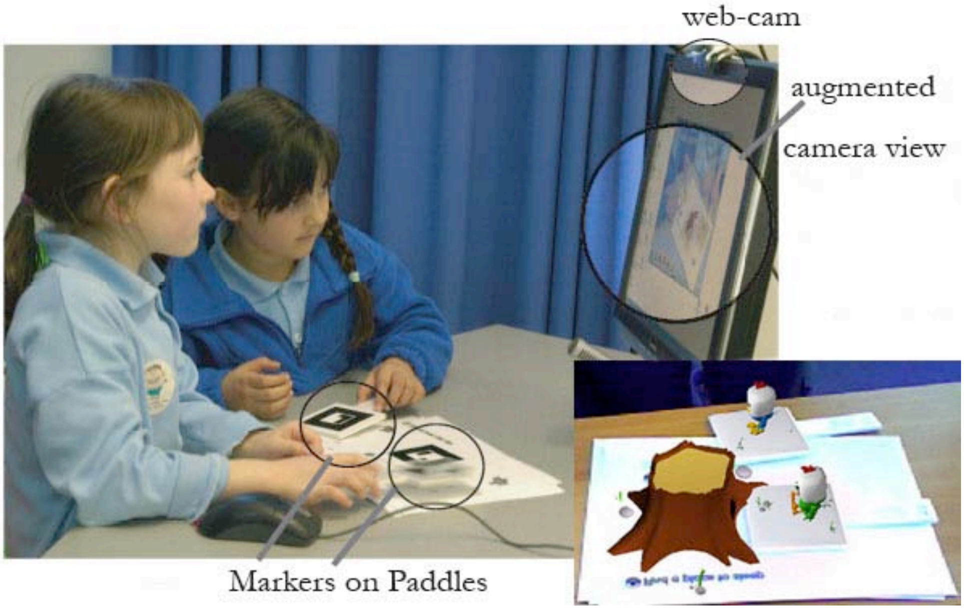

Figure 1. Set-up of system, with children engaged in interactive sequence (sneaking around the fox, the fox visible on-screen). Inserted image shows on-screen view of the chicks (sitting on the paddles) in front of a tree trunk (a marker on the page)

The study was designed to explore the use of augmented books for early literacy education. Children aged 6-7 interacted alone and in pairs with the AR-Jam storybooks (developed by the BBC). Two groups of children with different reading skills and socio-economic backgrounds participated in the study. The first trial involved children that had been identified by teachers as 'eager readers' (reported on in [5, 6]). As a contrast, the second trial involved children of the same age with reading skills below their chronological age [11].

2.1 The Augmented Books and the Study Design

The BBC provided the HitLab NZ research team with two augmented storybooks created for their AR-Jam project. These employ a combination of physical story pages and desktop interaction (screen, mouse), and alternate traditional narrated text pages with interactive sequences. On text pages (on-screen) the children can either read by themselves or listen to a recording. By clicking on buttons on the screen they can navigate through the story and start interactive sequences that have them interact with physical pages and paddles (see figure 1), seeing an augmented view on the monitor. The paddles serve as tangible input devices. They *represent and control* the main characters of the story while the paper pages constitute the setting (and other characters) for interactive sequences, organized as a series of physical pages.

The augmentation is based on AR Toolkit markers on the pages and paddles that are detected by a web-cam [3] and are replaced in the video image with computer-generated, animated 3D images. The augmented book thus becomes visible on the screen when pages and paddles are in camera view. The pages usually have 'hot spots', indicated by a grey outline. The markers are replaced on-screen with a relevant object for the story. Placing paddles on a hot spot triggers story events – in figure 1 (on the right) the chick will inspect a hole in the tree-trunk. A web-cam connected to the computer and positioned on top of the screen allows the technology to be used in most classrooms, being a low/no cost set-up. However, this does not provide a fully integrated view of real and virtual objects, unlike other AR-set-ups using head-mounted or hand-held see-through displays.

We used two storybooks. "Big Feet and Little Feet" tells the story of two little chickens, left outside the hen house in their eggs, who have to overcome several obstacles to escape a fox and find home. "Looking for the sun" has four insects (thus four paddles) that try to get to the sun. The chick story was specifically written for the AR-Jam, the other was adapted from a book by Rob Lewis.

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 corresponds to key stage 1 (age 5-7) in the UK system. For the first trial, avid and good readers were solicited from a nearby school in a middle-class neighborhood. Three pairs and three individual children each 'read' and interacted with one of the two stories (18 children in total). Supervised by the researchers, one child respectively pair at a time read and interacted with the storybook. Then, each child was interviewed individually. Analysis was open-ended, iteratively evolving and collecting categories and issues for further analysis. We employed both stories for wider insight into relevant design issues. The videos were analyzed collaboratively by the two researchers, iteratively collecting recurring issues and developing detailed notes of the children's interaction, transcribing talk and manual interactions.

As a contrast, the second trial involved children with reading abilities below their age who are hesitant about books. The trial was organized as part of one of the Learning Centre's 'book wizards' workshops conducted for a school serving a low-income socio-economic neighborhood. For this trial we used only the story about the two chicks, as we had identified a range of interaction problems with the other story. We further limited the trial to the pair condition (six pairs). Analysis followed the same approach as before.

2.2 Expectations of Physical 3-D Behavior

This paper focuses on one of the findings from this study, the children's expectations of the augmented paddles to follow physical laws of the 3-D world.

These expectations of 3D physical behavior seemed to be triggered by the tangible input devices in combination with the visual system feedback. The tangible input devices – paddles – have the physical affordance of allowing for manipulation in 3D space (Norman [15] talks about the 'real affordances' of physical objects in contrast to 'perceived affordances' that the user sees, on-screen objects having only perceived affordances). The augmented view provided on-screen reinforces the impression of interacting in 3D-space, because the markers'

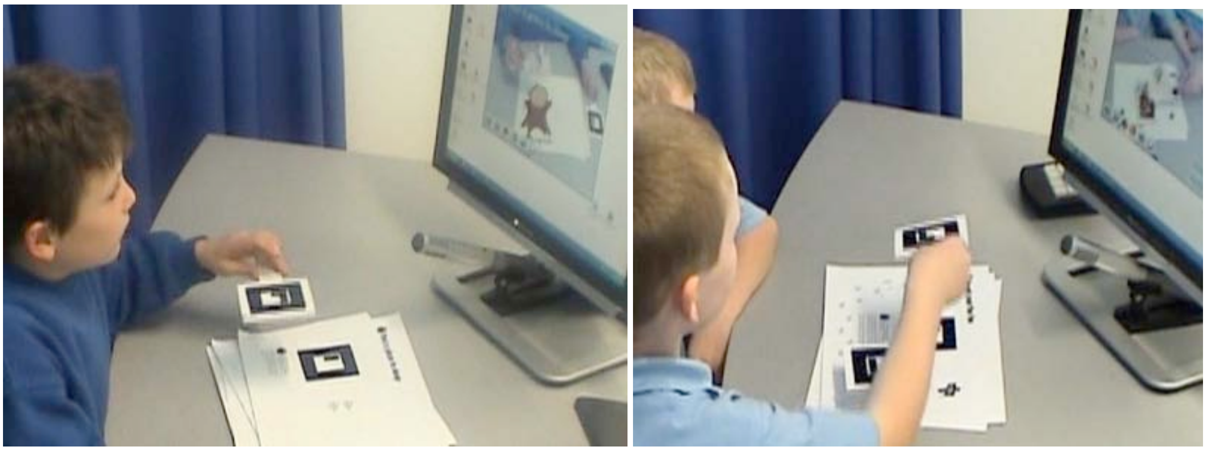

Figure 2 Trying to sit on top of the tree trunk and attempting to 'jump over' the fox

size and orientation are tracked and the digital objects (which on-screen are overlaid on the markers) are shown in the corresponding perspective view. Yet the story engine, that determines the effects of interaction, interprets the position of optical markers as a 2D point in the camera picture, ignoring orientation and height. A further limitation of the system is that markers need to be visible and paddles carry markers only on one side. Occlusion results in the virtual object disappearing. Objects can thus not be turned upside down.

We observed children attempting a whole range of 3D-interactions with the paddles, trying to make the digital characters (visible on-screen, on the paddles) act in 3D space. Evidence for these expectations of physical 3D behavior stems not only from the children's visible behavior, but can also be found in their talk. We saw children trying to let their chick sit on top of a (virtual) tree trunk by holding their paddle high above the tree visible on-screen. They tried to jump over obstacles, moving the paddle in an arch over the obstacle visible on-screen, (a meaningless motion for the software system). When aiming to make an object move off the paddle onto the ground, several children held their paddle in a slight angle and wiggled it, as if trying to let the object slide down, hoping for gravity to help. And quite often children would mimic a walking motion when moving the paddles, similar to the way they might move a doll during play. In the next sections a set of detailed examples from our notes and transcriptions from the videos is presented and discussed.

2.2.1 The Physicality of Cracking Eggs

An interactive sequence that had most children instantly refer to physical interactions with real objects was the story opening for 'Big Feet and Little Feet'. The story begins with the mother hen having forgotten to bring her eggs into the hen house at night. The children see eggs on their paddles. Bringing them closer to each other makes one chick say "Lets do it again" (this is intended by the system designers to provide a clue to children that the eggs need to be knocked against each other). We saw a wide diversity of different attempts at cracking the eggs open. 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. Both interactions result in the markers being occluded.

In this example, two boys rather playfully attempt to crack the eggs. They repeat this interactive sequence a couple of times, enjoying themselves. Even though they are successful, this is often quite by coincidence (the markers being next to each other for the camera) and they do not identify the 'correct' way (even though they repeat this 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 camera). On the screen this looks as if knocking the eggs' heads against each other, a sensible action in the physical world. Having tried this a few times, they bang the paddles onto the table face down (the markers invisible). Ken starts, and Tom imitates him almost immediately.

After a while Tom takes the paddles and whacks one paddle, the marker facing downward, onto the other paddle, the marker facing upward. This has the paddle on top hide the lower one. The markers are only briefly visible during this motion. Somehow the eggs finally crack up. 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, visibly enjoying themselves. After a while of doing this, Ken bangs his paddle with its edge onto the table.

In this short sequence we see a wide range of different actions one might do when trying to crack real eggs. Interestingly the children seem to identify the paddles as 'the eggs', even when holding the paddles in a way that occludes the markers, thus having no view of the eggs on-screen. Quick movements and fun experiments were rather typical for this 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 upward. Yet the many instances throughout story reading where the markers were occluded (by holding them in an extreme angle or by moving one paddle over a marker) shows that this is not natural behavior but requires conscious effort.

2.2.2 Jumping On and Over Things

Often children attempted to employ the third dimension in their interactions with the story elements. They for example tried 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 arch that on-screen indeed arched over the fence. This example is from two boys, who just saw the tree trunk appear on-screen after the paper sheet with the corresponding marker is put on the table.

Ken asks his friend "so what do you do, climb on it?" and moves his paddle over the tree trunk. As nothing happens, he moves the paddle slowly towards *the tree trunk, and eventually the animations are triggered as he moves the paddle over the hotspot on paper.*

The spoken question provides us with additional evidence of children's expectations to be able to interact in 3D, analogue to the natural world. Figure two (left) shows a boy in the individual reader 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 story engine – the children have to position the paddle onto the hotspot next to the tree trunk, which makes the chicks inspect a hole in it.

2.2.3 Letting Objects Slide Down

The tendency to refer to a physical world analogy posed a hurdle for most children asked to let the insect characters in the 'Looking for the Sun' story build a tower. The children need to make the insects stand on each other; the intended challenge being to find out in which order (smaller animals on top of larger ones).

The children struggled not only with finding the right order, but also with putting the paddle on the 'hot spot' next to the 'tower location' on the sheet in order to make their character jump onto the ground or onto the shoulders of another insect. We saw some children trying to make the insects slide or fall from the paddle, following laws of gravity. Children reading the other story, when required to let the chicks drop stones that they were holding, often held their paddle in a similar slanted angle, as if hoping for gravity to make the stone drop down. We here give a detailed example from the 'sun story' (Claws, Ant, and Scuttle are the story characters).

One insect is already on the ground and two girls now try to make another one stand on its shoulders. Alice takes a paddle and lays it directly onto the hotspot, upside down (the marker invisible for the camera). Then she tells her friend Clara: "No, get Claws". The tower tumbles down, and Clara fumbles for another paddle. Alice insists: "It should be Claws first". 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 4 (left) shows this hand posture. Then Alice takes the next paddle with Scuttle, but holds it upside down and sideways (the marker invisible for the camera) onto the hotspot. She then turns the paddle around, holding it vertically upright (as if trying to let Scuttle slide down). Her friend 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 in the correct position. Alice now does the same with the next paddle, holding it first upside down, then upright and wiggling it.

They start to discuss in which order the animals are on the tower and which orders they already tried. Again, the tower tumbles and they have to start all over. Clara takes the paddle with Crab, waves it around, but doing so occludes the marker on the sheet with her paddle. Alice now tells her to "push him down", and takes her hand, tilting hand and paddle so the paddle faces downward (see figure 4, right).

Figure 3. Building a tower with the paddles

One child's behavior is copied by her friend and vice versa, something we already noticed with Ken and Tom. Children imitating each other could just as well be picking up a useful 'how to' behavior as be iterating the same non-goal-leading behaviors over and over again. Still, overall children seemed to profit from working with a partner, getting less badly stuck than individual readers [6], and showing more signs of play and enjoyment.

The rather coincidental successes of the girls (after some wiggling) reinforce their belief of having found the best way to make the insects jump off the paddle. At the end one girl verbalizes her current understanding by teaching her friend to "push him down" and demonstrates how to do things. This makes explicit the children's assumptions.

The sequence further shows some general difficulties with the system, as the markers are easily occluded, especially with excited children acting simultaneously. Furthermore the spatial order of the intended tower needs to be translated into sequential movement of paddles, a cognitive challenge that requires abstraction.

Additionally, several children attempted to stack the paddles, literally building a *tower* of paddles (figure 3). 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 the task of building a tower was interpreted to refer to the paddles. We give a short example.

Kathy takes the first paddle and aligns it with the marker on the sheet. The marker is recognized. She keeps the paddle in place and puts the next paddle on top of the previous one. The tower (of two insects) tumbles. Her friend Lea puts her hands in front of her mouth ('oh no' gesture). Kathy explains: "Oh, you have to get them right on top of each other" and aligns the paddles as 'tower'. Then she puts the third paddle on top, and takes the fourth, Lea reaches over and aligns the paddle tower.

3. DISCUSSION

We might conclude that interaction could be enriched by more explicitly exploiting physical analogue behaviors, using them as interaction metaphors. Some researchers have quite

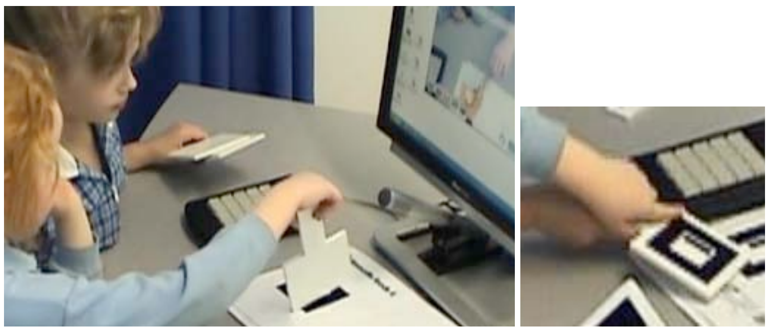

Figure 4. (left) Trying to let objects slide from the paddle by holding it slanted. (right) One girl grabs the other's hand, instructing her to "push him down" and demonstrating how to hold the paddle.

successfully developed interfaces based on the 'physical effects principle', such as a handheld calendar that scrolls to the next day if tilted [7]. But a more cautionary lesson is also recommended.

The tangible input elements (paddles) in our study worked rather too well in terms of encouraging physical interaction, users assuming physical world affordances and laws to transfer to the corresponding 3D objects. This inclination might be problematic for other tangible systems as well. Even though adults might be less inclined to expect physical-analogue behaviors, initial intuitiveness of interaction will break down at some point, shifting from 'ready-to-hand' to 'present-at-hand', because the input element is not transparent any more, becoming an object of investigation in itself [4].

In the remaining space I will attempt to get a clearer understanding of what our observations mean for the intuitiveness of tangible input elements ('elements' referring to their stand-in character in contrast to generic input devices) and the use/virtue of physical affordances. A range of concepts and analytical constructs from the literature are utilized in this attempt.

Beaudouin-Lafon's [1] analysis of 'directness and transparency of manipulation' provides a starting point. Directness is split into three aspects, the *degree of indirectness* (spatial and temporal distance between tool interaction and effect), *degree of integration* (relation between degrees of freedom of the input tool and the interaction tool), and *degree of compatibility* (similarity between manual actions with interaction tools and reactions of the manipulated object). The paddles are input tools and at first sight appear to be identical with the interaction tools (the markers???) in the virtual interaction space, where they control interaction objects.

The physical affordances of the paddles provide complete freedom in manipulating them in 3D space. The virtual visualizations seem to follow these faithfully (while markers are visible). This indicates good compatibility. The definition of 'degrees of compatibility' does not address the expectations of physical laws, which would e.g. dictate that an object falls from a paddle if this is held in a steep angle due to gravity pulling against friction. What does compatibility mean in this specific context? Some indirectness is created by the need to look at the screen to see effects, but children usually focused on the screen, where indirectness ceases to exist, the virtual objects clinging to markers. Position and orientation of markers in the video image (interaction tools) are interpreted only as a 2D-position for the story engine. Identity of paddles with interaction tools thus only holds for the visualization and not for interactive behaviors. The paddles and markers thus fail in terms of integration, but do quite well in terms of indirectness (low) and compatibility (high, if the definition refers only to the similarity of the shape of movement). This conceptualization of directness thus does not cut to the core of the problem. It does however point to the fuzzy role of paddles – are they interaction object, interaction tools or just input devices?

One risk of exploiting physical-analogue behaviors, interpreting 3D positions of paddles, might be the long road of refining a simulated physics engine. The affordances of physical objects are potentially endless (cp. [14, 16]); we observed various unexpected interactions with the paddles, them being turned around, hit on edges, hit against each other, being piled, tilted and slanted, moved in an arch etc. The more of these physical behaviors the system detects and makes the digital world act in accordance, the higher the expectations rise. And the more confusing the eventual breakdown...

This may be quite similar to the experiences HCI gained with the use of metaphor, which inevitably break down at some point. Metaphors are useful in helping users to map familiar to unfamiliar knowledge. But relying too much and too literally on metaphors in interface design, making objects look and behave exactly like the physical entity used as analogy, has sparked a good amount of criticism (and often resulted in overly complicated interfaces) (cp. [18, pp. 61]). Different from on-screen interaction (including touch screens) 3D physical form with tangible input elements is not merely a metaphor, clearly represented in 2D space, limited to this space and representation format. We can differentiate between an object and its picture, can move between seeing the object in the picture and seeing a flat canvas with some colored patches. Knowing that the depicted object is just an optical illusion which does not have the same properties as the real object allows us to interact with it on two levels at once – taking it as a stand-in or as a reference for the depicted object while knowing it is just a picture.

Users have learned that desktop display metaphors are not to be interpreted literally and tend to be rather cautious in this regard nowadays. Tangible objects on the other hand have real physical affordances, and these are even more inviting than visual metaphors and raise expectations that are difficult to resist or to disregard. Norman [15] points out that the designer can manipulate real affordance (which only exist in the physical world), feedback to interaction, and perceived affordances independently of each other, and that sometimes it would be best to hide the real affordance. In the case of the paddles, there exists a mismatch between the real affordance of the paddles to be moved in 3D space, the visual feedback, which creates a perceived affordance for the user, seeing the augmented objects faithfully hanging onto the paddles in 3D space, and the actual system behavior. As Norman says: the "power of real and perceived affordances lies (*in the*) real, physical manipulation of objects" – but this also creates a risk of creating suggestions that are just too powerful.

Fishkin [8] in his categorization of tangible interfaces introduced *embodiment* (linking of input to output focus and the users' impression that computing is embodied in the object) and *metaphor* as categories for analysis. Metaphor refers to whether the system effects are analogue to the real-world effect of similar actions – the 'physical effects principle' [7]. Metaphors can be by *noun* (similarity in form or appearance) and *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 and a weak verb metaphor (movement).

On a superficial level the paddles are close to the notion of 'haptic direct manipulation' [10]. Yet structural similarity of manual actions with effects repeatedly is ruptured. With the augmentation only on-screen, it is not clear conceptually *where* the interface is – on-screen, in the space of manual interaction, or in both arenas? The children seem to identify the paddles with the characters; the paddles for them are *the* interaction objects. While the visual mapping (attachment) of digital objects to paddles is simple and literal, the effects of users' actions are less evident – the structure of input actions is only indirectly connected with the effects on interaction objects. The inherent feedback from the paddles conflicts with the augmented (functional) feedback on-screen [19]. This makes it difficult to discern the relation of actions to effects, the children e.g. thinking that it is the banging motion that makes eggs crack.

[10] distinguishes the basic syntax of interaction, which should be easy to explore when manipulating objects (syntax refers to basic actions like moving from A to B and seeing an effect related to A and B), and the semantics of interaction (referring to more detailed and domain-specific effects of actions). Intuitiveness thus is relative to domain knowledge, and 'intuitiveness' might have levels. Hurtienne and Israel [11]

recently discussed how intuitive interaction can be thought of as relying on several layers of knowledge (innate, senso-motoric, cultural, expertise) and proposed 'image schemas' as basic metaphors (relying on embodied experience) that can provide intuitiveness. Physical laws may be a simple example of 'semantic directness', referring to how the application context is mapped with objects and operations/manipulations. Because the children see 3D objects on-screen they expect them to behave like the same type of 3D objects in the physical world.

4. CONCLUSION

This paper re-analyzed findings from a user study of an augmented book highlighting problems resulting from a mismatch between the affordances of physical interaction devices, users' mental models, and the actual capabilities of the digital system. Children reading an AR book expected animated augmented objects (which they could move around via optically marked paddles) to follow laws of the physical world, waiting e.g. for gravity to let something slide down or trying to jump over objects. The tangible input elements (paddles) encouraged physical interaction rather too well, children attempting actions that the system could not detect or react to, resulting in repeated small breakdowns of intuitive interaction.

The affordances of physical objects are potentially endless. This means that even if we thoroughly user-test physical interaction elements, hoping to spot all behaviors users might come up with, we cannot be fully sure of covering all possibilities. An optimal physical object that *only* has the desired affordances may not exist. In the case study discussed, constraining movement of the paddles (e.g. mechanically) would be very complicated and – as I feel - would overly restrict the interaction and harm the playful experience.

The real affordances of tangible objects seem to be very difficult to resist; in our case study they were suggesting a strong 'verb' metaphor. The discussion so far points to the role of digital visualizations in enforcing children's expectations of physical world 3D-bevhavior. The augmented feedback on-screen creates a promise of 3D-ness, but the structure of manipulation is only indirectly connected with the effects on objects. Even though the mechanical manipulation of paddles remains intuitive, determining what exactly the results of movements are (or which element of a movement caused a particular effect) often is not intuitive, requiring investigative attention and 'present at hand'-ness.

This is so far just the start of an analysis, which is to be continued. As a side-result it is interesting to note that the theoretical/conceptual approaches employed in attempting to pin down the problem do highlight aspects, but fail to provide a straightforward explanation. We still seem to be lacking the conceptual vocabulary to clearly denote what we talk about.

5. ACKNOWLEDGMENTS

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