# Beyond Affordance: Tangibles' Hybrid Nature

**Eva Hornecker**
Department of CIS, University of Strathclyde,
26 Richmond Street, Glasgow G11XH, UK
eva@ehornecker.de

## ABSTRACT

A prevalent assumption behind interface approaches that employ physical means of interaction is that this leverages users' prior knowledge from the real world. This paper scrutinizes the assumption that this knowledge can be seamlessly transferred to computer-augmented situations. TEI needs design strategies that acknowledge the hybrid nature of our systems. A change of focus is advocated: from support of intuitive use to the design of seamful mappings and the support of reflection and learning to enable appropriation and a better understanding of the systems we use.

### Author Keywords

Affordance, intuitive, natural, hybrid, reflection, design.

### ACM Classification Keywords

H5.2. User Interfaces: Haptic I/O, input devices.

### General Terms

Design, Theory, Human Factors

## INTRODUCTION

One of the most frequent arguments for tangible interaction is that it is intuitive because these hybrid systems leverage users' prior knowledge from the real world. This implicitly assumes we can combine the advantages of the physical and the digital world (physical input and digital functionality). Physical form and manipulability convey how to handle an object (*affordance*), building on experiences with the everyday physical world. At first reading, the idea that affordances improve an interface's intuitiveness seems a direct conclusion from the definition of affordances as the qualities of objects that allow a user to perform an action [17, 36]. Along with affordance, direct mappings and seamless couplings are described as TEI system design ideals [25].

This assumption has rarely been systematically looked into, although there is evidence that e.g. physical controllers for video games are not always intuitive [29]. The TEI literature tends to make somewhat casual references to the benefits of physical interaction and often shies away from investigating limitations (with some exceptions, e.g. [12, 27]).

This paper aims to contribute to a more principled discussion and a re-thinking of goals for TEI. I present a two-step argument. First, the assumption is scrutinized that knowledge from the real world can be seamlessly transferred to computer-augmented situations. A deeper investigation of the conceptual literature in HCI and TEI on affordance, mappings, and direct manipulation reveals a rather complex picture. This discussion is illustrated with a case study (previously presented in [21]). In this study, physical input tools raised unmatched expectations about how to interact, even though users quickly understood the general interaction model. The literature analysis surfaces questions whether designers can actually 'design affordances' (and control them), and whether leveraging prior real-world knowledge may mislead users to believe that these systems are 'like reality' (when they are not). While we should not give up on exploiting the benefits of physicality, we also need design strategies that acknowledge the hybrid nature of systems. This motivates the second step of the argument. A change of focus is advocated: from apparent immediacy to the design of seamful mappings and support of reflection, enabling appropriation and a better understanding of systems.

### Background

The rhetoric of 'natural interaction' is used widely across novel technologies such as multitouch and Kinect-style gestural interaction. Whereas the HCI community has started to realize that gesture input is not natural [38], we tend to believe that the interaction mechanism of TEI, direct manipulation of physical objects, is natural. Reliance on naïve physics, body awareness and skills are typical for what Jacob et al summarize as Reality-Based Interaction [26, 27]. This may reduce mental load and speed up learning [27]. Direct manipulation, guided by affordances, is commonly argued to support ease of use: "Our intention is to take advantage of natural physical affordances *[36]* to achieve a heightened legibility and seamlessness of interaction between people and information" [25]. Physical means of interaction are said to take advantage "of these haptic interaction skills" [24], "of users' well-entrenched skills and expectations of the real world" [26] and "of the immediacy and familiarity of everyday physical objects" [4].

While this relation is true to some extent, experienced designers and researchers know that it requires careful design

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and testing, and that quite often, some of the supposed design principles of tight constant mappings and coupling need to be re-thought [13, 14]. A closer reading of more recent articles reveals a more cautious phrasing: "The design challenge is a seamless extension of the physical affordances of the objects into the digital domain" [24], indicating that relying on affordance in design is far from straightforward. Unfortunately, only few publications reflect on what constitutes good design of affordances and mappings [1, 22, 43], or discuss the difficulties of crafting objects to communicate desired affordances [31]. Jacob et al highlight that reality-based interaction principles should at times be traded off against other goals, such as efficiency computational power, versatility, accessibility, technical feasibility and physical ergonomics [27]. The literature on tangibles in education has highlighted that systems which are easy to use and allow for rapid quick-fire action can be detrimental for learning [39]. As we will discuss here, this has wider implications beyond educational scenarios.

## ILLUSTRATIVE CASE STUDY: THE AR-JAM BOOKS

First, a case study is briefly introduced that will serve as an example to motivate my inquiry and illustrate the discussion throughout the first part of the paper. The AR-Jam books were developed as part of a BBC-Jam project on literacy education and originally evaluated (for details see [21]) to investigate how young children interact with augmented physical objects, and whether augmented books can motivate children's reading.

One AR-Jam book tells the story of two little chicks, who need to hatch from eggs, overcome several obstacles, and find home. The books comprise text pages and interactive sequences. During the latter, children interact with tagged physical objects while watching an augmented live video image on-screen. They control the story's main characters by moving physical paddles that carry these (see figure 1) and have to help them achieve their goals. The paper pages provide the setting for events. A webcam is aimed at this space. Pages and paddles carry visual markers, on which animated 3D images are superimposed in the video image on-screen. Placing paddles on a hotspot on a page, indicated by a grey outline, triggers a predefined event. There are some limitations to this setup. Paddles only work properly when markers are visible to the camera. Moreover, paddles can be moved freely in 3D space, but only 2D coordinates are interpreted for the story action.

**Figure 1. Left to right: Setup. On-screen scene, 3D animations over markers. Page and Paddles.**

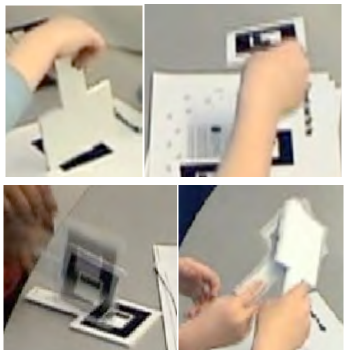

**Figure 2. Sliding, jumping. hitting paddles.**

Several considerations governed the system design. The familiar form of a book was thought to make it easy to step through a story. The designers wanted children to be able to pick up and move markers to manipulate a character. Paddles have a handle and a plate. Handles reduce the risk of fingers covering markers. Furthermore, paddles impose direction, being held like a frying pan. This ensures that users always see the characters from the front.

34 children aged 6 ½ to 7 (the age group the books were made for) took part in the study. 28 children read the story in pairs, six on their own. Although children quickly understood the general model of interaction, they often attempted interactions the system could not recognize. They struggled to understand what exactly made the system react, and then tried 'more of the same'. They moved paddles for a simulated jump or hit them against other objects to crack the eggs that the chicks are initially stuck in. Interpreted positively, the books allowed for playful exploration. But over time, children grew annoyed and frustrated if the system did not react. A systematical analysis of video data from all children [21] revealed that they attempted a wide range of 3D-interactions and seemed to expect the augmented objects to behave just like real objects and obey naïve physics laws. Moreover, they held and moved paddles in ways afforded by their physical form, but not anticipated by designers. Many children bashed paddles into other objects to crack the eggs, on the table, into each other, and even against their own head (figure 2), or moved paddles in an arch over objects visible on-screen to jump over obstacles, when instead they had to move *around* the fox or reach a hole in a fence. Wanting to drop an object, some held the paddle at an angle and wiggled, hoping for gravity to help.

Two factors seem to foster expectations of augmented paddles to behave like real-world objects. The paddles have the 'real' affordance of allowing for 3D movement. The augmented view on-screen (figure 1 middle) reinforces the impression of acting in 3D-space. Digital objects are shown in perspective view, indicating 3D space relations. In response, the children expected paddles' height and 3D-movement in relation to other objects to be meaningful for the story action. The cause-effect relationships that underlie children's expectations are naïve-physics laws such as gravity. Analysis also revealed that this was context-specific, some behaviors only occurring in specific situations. For example, scenes that required moving paddles in relation to other objects seemed to raise expectations of being able to interact in 3D. Jumping over another object only occurred when this object was introduced as an obstacle.

Behaviors that indicate (unfulfilled) expectations were identified and categorized, such as: 'exerting force will crack the eggs', and variations thereof. The video data was coded along categories and variations (thirteen variations of hitting paddles, four of 3D actions). Two-thirds of children did some of these, with high variability in how many types each child carried out (between zero and ten), while some variations were done only by a few children. This variability demonstrates how difficult it is to predict user behavior. Although all of the children quickly understood the general principle of interaction, they experienced subtle difficulties that at times resulted in frustration, the system failing to react as expected. Moreover, the system evoked a large variety of interactions not anticipated by designers. This was even though the AR-Jam had been the result of an iterative development effort with repeated user testing of prototypes.

## UNFOLDING AFFORDANCES

A review of the literature on affordance, mappings, and direct manipulation reveals that these concepts are more complex (and contested) then usually portrayed, and highlights the difficulties of 'leveraging real-world knowledge'.

### Affordances, Constraints, and Mappings

The concept of affordances has gone through a history of enthusiastic take-up, confusion, and attempts at clarification. According to Gibson [17], affordances denote the possibilities for action that we perceive of an object in a situation. They exist relative to the action capabilities of an actor. Norman [36] adapted and introduced affordances to HCI, and later-on [37] differentiated real (physical) from perceived affordances. This terminology diverges from Gibson for whom affordances exist independently of being perceived. Norman states that designers can independently manipulate real and perceived affordances along with feedback. The 'real affordances' of physical objects [37] seem to favor tangible input, whereas GUIs only have *perceived affordances* - visuals that advertise the affordances and rely on cultural conventions – the entire screen affords clicking, graphic design relying on learned convention.

Some authors reject the notion of perceived affordances. These provide additional information, but cannot be interacted with and thus do not afford action. Distinguishing between an affordance and its *visibility* (or the information advertising it) highlights how the two can differ and interact [16, 34]. With no information there is a hidden affordance (e.g. a secret door) that relies on knowledge [16]. Information suggesting a nonexistent affordance creates a 'false affordance' [16] or misinformation [34].

One could interpret the AR-Jam's on-screen visuals as misinformation (seeing the chicks go over a fence event although there is no jump). The children saw 'wrong' action possibilities in terms of the semantics of performed actions. The paddles nevertheless afford the actual movement and the on-screen visuals seem to confirm it. The augmented objects hang faithfully onto paddles in 3D space, tightly coupled to mirror their movement.

When Norman [36] introduced the notion of affordances, he discussed these in tandem with constraints, which limit options and either remove or guard affordances. Constraints and affordances in concert can guide users through sequences of action. Constraints could be used to restrict paddle movement, but in the case of the AR-Jam would limit playfulness, counter to its purpose. Moreover, this would not address the main issue: *children's expectations of real-world analogous behaviors*. It is not the movement of paddles that is difficult to understand - these are continuously and seamlessly mapped to the movement of virtual characters on-screen. The issue at stake is the system's *semantic* interpretation of what moving paddles means. Children can only mimic the action (jump), but not the desired effect. The coupling of paddles to characters on-screen is very strong, and makes children treat the paddles *as-if* they were the character, expecting further characteristics and action possibilities of the real thing to apply. This demonstrates that continuous tight mappings can create confusion when there are more complex and indirect levels of effects.

Fishkin [15] suggests the 'physical effects principle', where system effects are analogous to real-world effects of similar actions, based on naïve physics. But with digital elements, it may not always be clear how physical world laws should apply, or which objects they should act upon. Chatting [9] found that users who navigated a map by tilting a tablet PC preferred the metaphor of 'a focus point rolling downhill like a marble' (tilting where you want to go) over that of the 'map as tablecloth' (the map slides down). This is although the focus point is only an imaginary object, whereas a map has a physical analogy. The interaction metaphor of 'focus point as rolling marble' is not a straightforward translation from real-world effects. In this case, it is not immediately evident for the designer *which* knowledge from prior real-world experience users will apply to make sense of their interactions with the digital device. For devices with complex functionality, such mappings would need to be developed in a consistent way for a rich set of digital actions.

### One object, many affordances

While the augmented paddles afford the desired interactions many children reacted to other cues. Affordances are often described as something the designer can utilize and design into a system, providing users with cues on how to interact. However, similar to the use of metaphors in interfaces, which have a creative potential and where unpredicted user interpretations escape the control of the designer's intent [5], physical objects have a potentially unlimited set of properties and affordances [28, 42]. Designers and architects exploit this purposely by collecting and displaying objects and materials for inspiration. A piece of fabric may catch their attention because of its color, texture, or sound.

"We possess nearly unlimited modes of interaction with the physical world" [33]. While the properties of digital objects need to be explicitly created, physical objects inherit a multitude of incidental properties (and affordances), for example from the material they are made from. This is a benefit of tangible objects, but also a design challenge. The sensory richness allows for expressiveness and increases variety of interaction. Systematic studies of users manipulating cubes of varying size, shape and material [44] and of a museum installation controlled by a cube [46] found numerous handling variations for selecting one face of this seemingly simple shape. It seems almost impossible to anticipate which physical object properties users will find remarkable and react to, or to restrict affordances to the desired ones. Price et al [40] observed that during a learning task on the behavior of light children using a tangible tabletop system (see Figure 3), attempted to pick up a (real) torch from the surface, where it could not be tracked, resulting in confusion. That the torch was shining (virtual) light despite being switched off raises further issues regarding user expectations from real-world interaction. Price concludes that literal physical correspondence may raise tradeoffs, suggesting ways of interaction that do not translate from the real world to the system world.

### Affordances do not exist in a Vacuum

For Gibson, affordances "exist whether the perceiver cares about them or not, whether they (are) perceived or not" [16]. They are independent of actors' needs and goals. Whether we take notice of them depends on whether we see and understand the perceptual information available. Users perceive [34] and creatively select the affordances that suit their aims, understanding of the system, and the situation: affordances emerge. The context-dependent occurrence of behaviors during the AR-books interactive sequences is consistent with this view; children interpreted the affordances of the paddles in relation to the story situation, bashing paddles to crack eggs, and jumping obstacles.

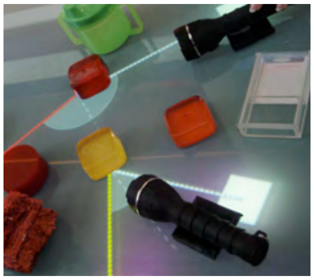

**Figure 3. Price's [40] tangible tabletop system simulates the behavior of light.**

The original affordance concept has been critiqued for its limited emphasis on cultural knowledge and experience required to interpret object properties and functionality [45, 47]. The case study provides another twist to the story, showing how affordances can go unnoticed if they do *not fit* with real-world experience and cultural knowledge. The AR-Jam paper pages could be moved around (and held up to the camera) to manipulate the view of the scene. This affordance is not hidden [16], but nevertheless went unnoticed. One reason might be *expectations*: children are used to books having a standard orientation. Experience disfavors moving pages about. Furthermore, in everyday life we move our view of the environment by moving ourselves; it is physically impossible to move your environment. Moving pages to change viewpoint is incompatible with children's experience.

### When the World Disobeys its Direct Manipulation

The 'optical illusion' of the animated AR-book characters moving on-screen as desired might have a further side effect. At first, manipulation of the paddles seems to grant direct control. AR and tangible interfaces employ the metaphor of a model world that is directly manipulated [23] rather than one of interpersonal communication. It is argued that a model-world, where users perform actions instead of describing them abstractly, provides a feeling of direct engagement [23]. The interface presents a world of 'behaving objects' that behave 'as if they are the real thing' and provides instantaneous and continuous feedback. This is precisely the impression given by the on-screen illusion of the AR-books, due to the direct mapping of paddle movement (when markers are detected) with augmented characters on-screen. Yet at times, the model world refuses to behave, even if the intended action is mimicked. Direct manipulation in this case provides a feeling of direct control, but then contradicts what the user saw (e.g. a jump). The confusion evoked by this disobedience of the world might be more severe than a failure of indirect interaction methods that employ a conversational model of interaction. Interpreting all possible user actions would require a full physics simulation engine, and raises new questions of how actions should be interpreted meaningfully in relation to the system functionality (cf. [3] on expected, sensed and desired actions).

### Summary: The Utility of Affordances

The vocabulary associated with the affordance concept has enriched the analysis of the case study. Gibson's original notion and its extensions explain how previously unnoticed affordances can be noticed with new goals or changes of context, shedding light on some of the issues encountered with the AR-Jam. A refined understanding points out the role of accompanying information that can communicate the purpose of an afforded action, its effect and meaning within the system world [47]. It was argued that it is very difficult to restrict the set of affordances of a physical interface to those intended by the designer. This is not necessarily negative, as this sensory richness also offers room for interaction expressiveness and allows users to creatively appropriate objects and devices for new aims.

The literature on TEI and TUIs tends to use the affordance concept in a rather lightweight way, hoping to utilize affordances to provide clues on how to operate a product. A stronger focus on the design of the information that announces affordances [cf. 47] along with care to avoid misinformation [16, 34] might be needed. Furthermore, the literature analysis has revealed that cultural knowledge and experience are often necessary to interpret the information about affordances and understand the functionality.

In particular, the novel functionalities of new technologies will often need translation and may not be intuitive, even if the affordances are there. This means it is becoming more important to make the hybrid and seamful nature of TEI systems visible, and to support reflection and learning, enabling the user to extend their understanding of the system and allowing them to accommodate and appropriate it.

## DEALING WITH OUR SYSTEMS' HYBRID HERITAGE

### The Power of Suggestion

The AR-Jam study demonstrated that the suggestions from the paddles were very powerful. Despite a persistent lack of positive feedback, some children repeatedly tried to let objects slide off paddles, hit and bashed them, and many forgot to keep markers in camera view. Clearly, most children did not stop to reflect. Stepping back and analyzing the system reaction implies that the tool stops being invisible and ready-at-hand, and becomes present-at-hand [8, 10, 6], requiring conscious attention. Intuitiveness is often equated with readiness-at-hand. But building on users' existing knowledge and skills with the everyday world only works as long as there is no need to reflect. Chalmers [7, 8] argues that the emphasis on readiness-at-hand in the literature on embodied and tangible interaction neglects reflective action which focuses on the tool itself and contributes to re-appropriating it for new tasks, enhancing users' skills, e.g. in learning a new technique, and breakdown recovery.

If the power of real and perceived affordances lies in the "real, physical manipulation of objects" [37], then these might also create suggestions too powerful to resist. This may be similar to the experiences in HCI with metaphor. Metaphors help users to map familiar to unfamiliar knowledge, but tend to break down at some point. Making interface objects look and behave like the physical entity used as analogy has sparked a good deal of criticism [5, 18]. Literal metaphors can even act as barriers from an effective understanding of novel functionality. Moreover, with 2D images we know that the depicted object is an optical illusion, and can decide to suspend belief anytime. With tangible input, we deal not just with a metaphor (for example, Ishii's bottles as containers of music [25]), but the physical world *is the medium*. Tangible objects possess physical properties that a visual depiction can only allude to. These are very inviting; they raise expectations that are difficult to disregard. This is because the human brain processes physical object properties and basic physical manipulations on a low cognitive level. The required sensorimotor knowledge is acquired early in childhood and frequently retrieved, enabling fast skill-based performance without conscious attention and control [35, 41]. Physical properties thus provide strong perceptual cues that can *bypass conscious understanding and action*. It is both advantage and problem that physical properties are directly perceived, rarely surfacing in consciousness, making it difficult to resist the interpretations they trigger. To disregard these, the user would need to step back, observe and control the interaction, which becomes present-at-hand [10] and thus stops to be intuitive.

### Beyond Nature

> "Initially AR seems a wonderful solution to a tricky problem, retaining all the advantages of our abilities as human beings to deal with physical objects, while benefiting from the computer. (…) Physical artefacts are useful precisely because they are so predictable. (…) In contrast, on-line systems are notoriously difficult to understand: other people, rather than the laws of nature, dictate how they work." [30]

Mackay [30] points out a core issue – digital artifacts are not predictable because they follow artificial laws. This not only refers to novel functionality, but also to the language of interaction. Matthews [33] argues that gestural interaction requires learning a new movement language: "Once more, we are no longer making use of our ordinary familiarity with the physical world, but only of our capacity for versatile actions and our ability to learn what they mean within the system. (… Movement grammars) appear to offer us the possibility to trade on our embodied, pre-conceptual familiarity with the physical world, but do not fulfill that promise in actuality" (cf. Norman's verdict [38] 'natural user interfaces are not natural').

System designers have to design a grammar of interaction. Digital systems are *not* the real world; it is their very strength to offer functionality unavailable in the real world. Furthermore, users need information to understand what this new functionality means. Affordances do not suffice - if intuitive interaction relies predominantly on spontaneous reactions that short-circuit conscious decision-making, then we lose mechanisms of recovery and reflection.

Tangible interaction and AR as examples of reality-based interaction have a mixed heritage from the digital and the real world. The digital system is largely invisible, and there is little analogy in the real world as to how it reacts. We need to take account of what may be sensed or not sensed, and of users' unexpected actions [3]. In addition, gestural and tangible direct manipulation do not support reflection on prior action well, as they constitute ephemeral, transient notations which cannot be reviewed, replayed or rearranged, having no visibility over time [2, 12, 40].

A major lesson learned from the Equator project [3] is that 'seamlessness' is an illusion. Tom Rodden in his TEI'07 keynote (see [20]) called to exploit the differences of media and discontinuities or seams (which are inevitable with sensor systems) as part of the experience, and to create systems

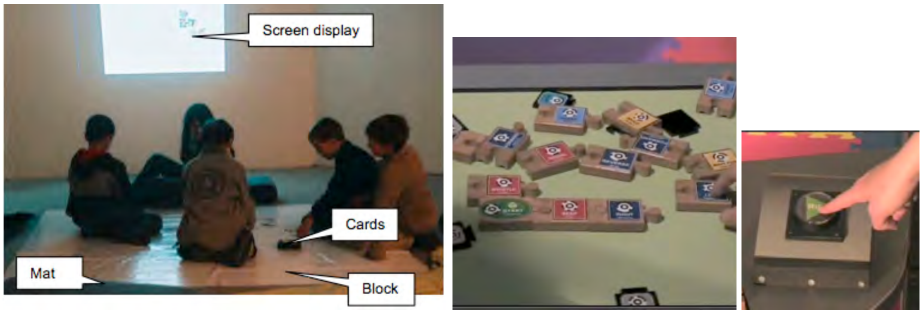

**figure 4. Decoupling control and display areas in programming on the floor (image from [13]). With Tern [19], the program is created off-line. Pressing the 'run'-button activates a camera to take a photo that is interpreted. (Images courtesy Mike Horn taken from http://hci.cs.tufts.edu/tern/tern.mov)**

that are open to appropriation. The challenge today is "how to reveal the invisible world of sensors, making it available as a resource for judgment" instead of hiding and making them invisible. In dealing with novel technology and unfamiliar functionality, users need the capability to reflect, consciously observe and control; they need information and support for learning to support recovery and skilful appropriation [1, 8]. Interfaces should oscillate between transparency and reflection, allowing the user to "step back and contemplate" [6] – media do not disappear.

### Representing Complex Domains in TEI design

Even though there are successful examples that employ seamless mappings, many real-world tangible design projects within complex domains revert to explicit breaks and seams. These are often due to the kinds of trade-offs that Jacob et al [27] mention regarding efficiency, versatility and expressive power. For example, Fernaeus and Tholander's programming environment for children [13] provides separate input and output spaces, violating one of Ishii's TUI design principles [24], and decouples parts of the functionality. The program is manipulated on the floor and the outcome projected to a wall (figure 4 left). Initial prototyping revealed that tight direct mappings between on-screen and tangible objects (cards denoting the simulation objects and behavior rules) made it impossible to reuse code and limited computational expressiveness. An extra layer of indirect interaction was added that explicates adding objects and assigning behavior to existing objects, requiring children to place a selector object on the floor and then place programming cards on it to be read and assigned to the designated object. This also means that the system does not continuously track objects. While violating the principle of direct and continuous mappings, this created new affordances for children to sort and spread out programming cards on the floor 'off-line' to prepare their work. This system design supports collaboration and reflection, as children can cooperate on planning programs, and compare alternatives before committing to put these on-screen.

Similarly, Maquil et al [31] separate selecting objects from changing attributes and moving them about on the ColorTable, a tabletop tangible mixed reality urban planning tool. They introduce a separate workplace for selecting objects and a monitor to display the content of selected objects. This provides an unobstructed view of the design situation (a map), without cluttering it with attribute displays. At times, to allow for wider views, the mapping is completely suspended, even though this might require users to manually reposition tangibles. Other successful TUIs give up completely on constant mapping, and require users to explicitly activate tracking and interpretation. With Horn's Tern [19], one pushes a button after assembling a program from tangible parts for the program to be read, interpreted, and executed. During the actual programming process, the system is offline, and does not provide any interactive feedback. All of these are examples where a TEI system gives access to new functionalities not available in the natural world and represents things that do not exist in nature. Where the representation has no analogy in nature, physical metaphors usually do not provide a consistent analogy.

Many successful systems known from the literature that employ continuous mappings either simulate real-world phenomena (e.g. the reflection of light) or emulate a physical setup (spatial planning tasks), augmenting these with additional information and options to adjust parameters (e.g. Urp and Illuminating Light [24]). The AR-Jam books seem a borderline case. While they emulate a situation (the storyline), they only intend to give access to *one* storyline – they are not a full-scale simulation. Systems such as Price's [40] tangible tabletop system for learning about the behavior of light (figure 3), which extends ideas from Illuminating Light [24], emulate the thing itself. Here the tangibles are fully simulating a physical object and do not have metaphorical nature (although they have added benefit functions). This motivates the hypothesis that seamless mappings work best when one can treat the thing as-if it were the signified object. This is easier if the system simulates physical behavior instead of providing novel functionality that doesn't exist in the real world.

Yet Price's studies [40] reveal a complex picture. For example, a co-located visualization (a tabletop shows the simulation of light beams as if it were inside and between the tangible objects representing a torch and prisms) promoted engagement and increased access, enhancing shared exploration, while projecting the simulation onto an adjacent wall slowed interaction down, giving more time for reflection. Although the co-located mode was easier to use, Price recommends design of learning activities that slow down and provide opportunities for reflection. This study also highlights how an apparent stand-in function can create conceptual confusion when tangible object and represented object do not fully coincide. Children believed "it is actually dependent on the real properties of the objects" [40], being surprised when a transparent tangible object behaved like a colored object, and wanted to pick the torch up to shine light from above. Similar to the AR-Jam study, children were tempted to believe the system behaves like the real thing. What was found to foster reflection was not the system itself, but the interferences between children's actions, and their need to coordinate their actions with this system, given there was only one light source.

Most attempts to determine learning benefits of tangible interfaces have been unable to find clear benefits [32], resulting in cautious messages, and sometimes even concluding that the ease of doing things with tangibles can hamper deep learning. Do-Lenh et al [11] found that Tinkersheets, a tangible representation of warehouse shelves used for learning about logistics, resulted in significantly better performance then traditional paper sketching in terms of the number of designs generated. But it did not improve learning outcomes, whereas paper sketching tended to do so. Do-Lenh et al [11] argue that the very fact that task performance was improved might be detrimental for learning – "the layouts were accomplished *too fast*", requiring less intensive cognitive effort. Sketching requires anticipation of consequences, with more effort needed for changes, which furthermore encourages students to discuss their actions with each other. It seems that opportunities for reflection need to be explicitly designed into a tangible system, and that this often means structuring the process in ways that enforce reflection, slow action down, and foster collaborative sense-making.

## CONCLUSION

The literature on tangible interaction has tended to assume that these hybrid systems can inherit the positive aspects of physical input and leverage users' prior knowledge from the real world. Their naturalness and intuitiveness was one of the 'selling points' for TUIs when this interface approach was first introduced. But slowly we are starting to realize how much effort is needed to fulfill this promise, and that a different approach may be needed at times. This is because computer systems by their nature are not like the real world, and because systems need to go beyond real-world behavior to be powerful. Natural interaction seems a 'holy grail' that is unattainable [cf. 38].

In this paper we went back to the conceptual and theoretical literature to investigate whether it explains the issues uncovered in the case study originally presented in [21]. This increased the skepticism regarding the ability to leverage real-world knowledge. The literature review revealed an under-utilized conceptual depth behind keywords such as 'affordance'. The affordances of physical objects are potentially endless and users creatively select those that fit their understanding of the system, their aims and the situation. Designers' capability to design affordances 'into' objects, let alone restrict them to desired ones is thus limited. In addition, constraints and information advertising affordances are just as important as affordances.

Especially with novel system functionality, users need background knowledge to make sense of it and help in going through complex sequences of action – but inviting affordances and tight mappings tend to discourage reflection. Support for reflection and learning is not only important for learning scenarios. Tasks, users, and use contexts continuously change and evolve, and then the ability to step back and reflect is needed to appropriate the system anew.

The discussion presented here adds to attempts such as [12, 22, 27] in understanding the opportunities and limitations in reality-based systems. None of the tradeoffs and conflicting objectives presented by Jacob et al [27] quite captures the issue focused on in this paper, that apparent realism may mislead users to expect the system to behave 'like the real thing'. We need to be cautious not to fall prey to what Bolter and Gromala [6] refer to as 'the myth of transparency' or 'myth of the natural interface'.

With this paper, I do not intend to dismiss valuable efforts towards designing and generating design knowledge for intuitively usable systems. What is hoped for is to trigger a discussion that acknowledges the difficulties in doing so, and the limitations of such an approach, challenging readers to think in new ways about what TEI systems are good for and how to design them.

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