

Exploring the Design Space of Shape-Changing Objects: Imagined Physics

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ABSTRACT

In this paper we describe the outcomes from a design exercise in which eight groups of designers designed and built hardware sketches in the form of playful shape-changing prototypes, generatively working with Rasmussen et al's [31] eight unique types of shape change. Seeing that shape-changing interfaces is a growing area in HCI design research and that authors often shy away from articulating the special qualities brought to a design by using changing shape to communicate information, we set out to explore shape changing interfaces through a series of sketching experiments through the support of Danish toy company. Eight design groups redesigned existing tumbling objects for children using electronic sensors and actuators guided only by the request to adhere to the client's design goal to inspire imagination and movement in users. The main contributions of the paper include indications for the further expansion of the design space of shape changing interfaces relating to the perception and understanding of behaviour, causality and the mechanics involved in shape change events, which we call "Imagined Physics." This concept is described along with additional insights into the qualities of shape changing interfaces coined in recent research in the field.

Author Keywords

Shape change; Playful objects; Open-Ended Design; Imagined Physics

General Terms

Human Factors; Design; Measurement.

INTRODUCTION

In Nature, the praxis of changing shape in order to communicate something is quite common. So common in fact, that it perhaps should not raise eyebrows when a blowfish expands its volume or a cat suddenly changes texture in order to scare an enemy. Nonetheless, the effect

is rather dramatic and shape change holds great possibility for contributing to a design if used with skill. Today, shape changing interfaces have found their way into various application areas, but the HCI design research community has only recently begun to categorize, define, and develop a vocabulary to make sense of the field, see [6,28,31]. While some examples are provided in these papers' taxonomies and in reviews by other researchers, the understanding of the categories of shape change and the supporting evidence for these categories is rather limited. For example, does it in fact make sense to separate change in texture from change in form [31], and if so, what are the aesthetic or experiential qualities of such changes in shape?

In this paper we explore the quality of shape-changing interfaces through a series of hardware sketches, each making use of different types of shape change to inspire imagination and movement. We borrow the term sketch from Buxton [4] to describe the designs, presented in this paper, since they are aimed at exploring and raising questions rather than testing out solutions. We used the framework, described by Rasmussen et al. [31] outlining different types of shape manipulations, in a generative manner to open the design space and developed a spectrum of sketches of interactive shape changing tumbling objects designed for open-ended play. . In the paper we use the term playful to describe the quality of open-endedness and having no obvious pre-defined use, which are essential to the tumbling objects manufactured by the client. The sketches were designed to evoke our understanding of the qualities and possibilities of various types of shape change in an interactive product, and consequently inform the underlying framework. The sketches use playful tumbling objects for children as an exemplary application scenario, in order to explore how shape change can display new ways of responding to and inviting for interaction. . Seeing that the products used for the redesigns were specially designed for young children, our work keeps that focus despite our findings could be of interest to other potential user groups as well.

The aim of the paper, beyond presenting the collection of novel shape-changing tumbling objects, is to apply them to reflect back upon the framework, described by Rasmussen et al. [31]. An furthermore to reflect upon them with

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regards to how they can contribute to a grammar that can help designers understand and articulate the qualities of using shape change as a means of interaction. We begin by reviewing research on shape-changing including work focused on playful objects and research that has expanded and informed the vocabulary of interactions with shape changing objects. Then the eight sketches are presented—each focused on a specific type of shape change and how that facilitates movement and imagination. This is followed by discussion based on the insights gained through the design process and related to the framework of shape change [31].

RELATED WORK

The integration of sensors, actuators and computing power into playful objects for children has been explored from a range of different perspectives within HCI, and yielded a multitude of different examples. From animating plush toys (e.g. [35]), to digital playgrounds (e.g. [33,34]), animated paper [20], shape-changing toys (e.g. [17,30]), open-ended interactive play objects (e.g. [2,36]) and many other inspiring playful interactive objects and concepts. We now discuss briefly research related to playful objects involving technology and shape-changing objects that have made progress in opening the design space of physically dynamic interactive systems.

In the area of shape-changing interfaces, playful objects have also received some attention. The field has explored the potential of making objects physically dynamic. Both Topobo [30] and Kinematics [26] present playful toolkit, which allows the users to explore movement and physical change. Topobo [30] is a construction toolkit, consisting of a set of both passive and motorized building blocks, which have the ability to playback physical motion in 3D space. The elements can be snapped together to construct dynamic biomorphic forms, which can be animated by pushing, pulling, and twisting the elements, and observe the motion repeatedly play back the motion. Kinematics [26] is a construction toy, which consist of both active and passive building blocks. Each block holds a specific functionality, e.g. power block, brain block or Kinematic Block, which are either a shape-changing cuboid (cuboid to parallelepiped), or a rotating block in the shape of a cylinder. Ninja Track [17], presents a different approach, where the shape change is used to switch between two states of play. Ninja Track is a shape changing toy, which can be used in different ways; It can change from a flexible whip into a rigid sword with the push of a button and augment the two types with the sound effects of the two types of play weapons. Ninja Track can also be used as a musical instrument, which can produce sounds depending on its shape and user interaction.

Some designers point to potential application of the explored type of shape-change, within the area of playful objects, such as: the physical kinetic surface of Kinetic Bricks [18] could be used as a construction toy for children,

or SpeakCup [37], which functionality could be used as a toy for social interaction in public spaces.

Shape change holds potential beyond the scope of playful objects, from small scale applications, such as dynamic buttons [10], shape-changing mobile phones [11,12], or wiggling attention seeking post it's [29] to large scale dynamic architectural elements, such as the kinetic façade of a parking garage at Brisbane airport [16], shape changing architectural structures [25], or visions of permeable architecture [5]. These are just fragments of the abundance of examples, which have sprouted from the field within the last decade.

Beyond the multitude of point designs, exploring the potential application areas, experiences and interaction that making the physical form dynamic enables, some papers have also pointed to the challenges, potential and limitations of the current technologies [6], providing toolkits [27], framing different aspects of kinetic vocabularies [28,31], introducing new technologies [8] and pointing to future visions for the field [15].

However, although more and more application examples of shape-change as an interaction modality emerge, and the field start to provide more general reflections, then how can the knowledge generated in the field, be used beyond as reflection on the existing body of work, but applied generatively, for example, to open the design space?

METHOD

The sketches presented in this paper are the result of a masters' course at a computer science faculty. The course was designed to explore the framework described by Rasmussen et al. [31], making specific experiments with each of the eight types of shape change identified in the paper, namely change in form, orientation, volume, texture, viscosity, spatiality, permeability, and the adding/subtracting matter from a compact body of material. The choice of using the framework as the point of departure for the explorations has three main reasons. First, the framework focused on the experienced form changes, rather than for example mechanical elements [28]. Second, the framework served as a simple tool for engaging with and opening the design space. Third, by assigning groups of students specifically to each of the eight types of shape change, the framework helped to encourage a wider range of prototype possibilities to inform back upon the understanding of the qualities and possibilities of various types of shape change. By assigning one type of shape change to each group, it created an artificially rigid division between the eight types. However, despite creating this division between the types, which often are interconnected, then, experimenting with one type of change as a starting point for each group helped to generate a broad range of examples to help inform the initial framework.

The focus of the course was to explore the notion of utilizing physical changes in form as means of interaction,

and to challenge shape changing interfaces by not simply adding shape change to known interfaces, but seeking to make use of shape change on its own premises.

The course was conducted with the support of the Danish design company bObles, which designs playful tumbling objects for children, following a design philosophy that dictates simplicity in material and concept, and aim to inspire imagination and movement with their products. The tumbling objects are made from solid EVA foam blocks and are quite versatile; they work equally well as furniture, building blocks and obstacles in a game of tag, or whatever a child might imagine.

The course participants were divided into eight groups of three or four people, and assigned the task to redesign a bObles' tumbling object using one specific type of shape change. Additionally, the design should meet with bObles' design philosophy. The shape change framework [31] was used as a way to open the design space, and broaden the exploration of shape changing interfaces. Participants were urged to develop their understanding of the properties of shape change through (hardware) sketching, drawing directly on Buxton's [4] understanding of the praxis. The

8 SHAPE CHANGE EXPERIMENTS

In the following sections we will shortly describe the eight sketches derived from the course, with regard to the type of shape change utilized, technical considerations in the construction and notes about the interaction with the sketch. Each of the eight sketches is illustrated in Figure 1, describing the conceptual implementation of shape change and a visualization of the design provided by the students.

benDy (Orientation)

benDy is a redesign of the U-shaped tumbling object called 'Elephant', and explores how change of orientation can be used to invite movement and imagination in children. The body is divided into pieces that can unfold the U-shape into a flat surface (when distancing all of the pieces) or other shapes (when distancing some of the pieces in various formations).

Interaction

When tapping the back of benDy one changes its shape. Soft taps will change the distance between individual pieces whereas a hard tap will make the shape fall flat (i.e. change the distance between all the pieces) in an instant. Moving away from direct manipulation, the designers introduced a 'wand' that would allow for the change of orientation

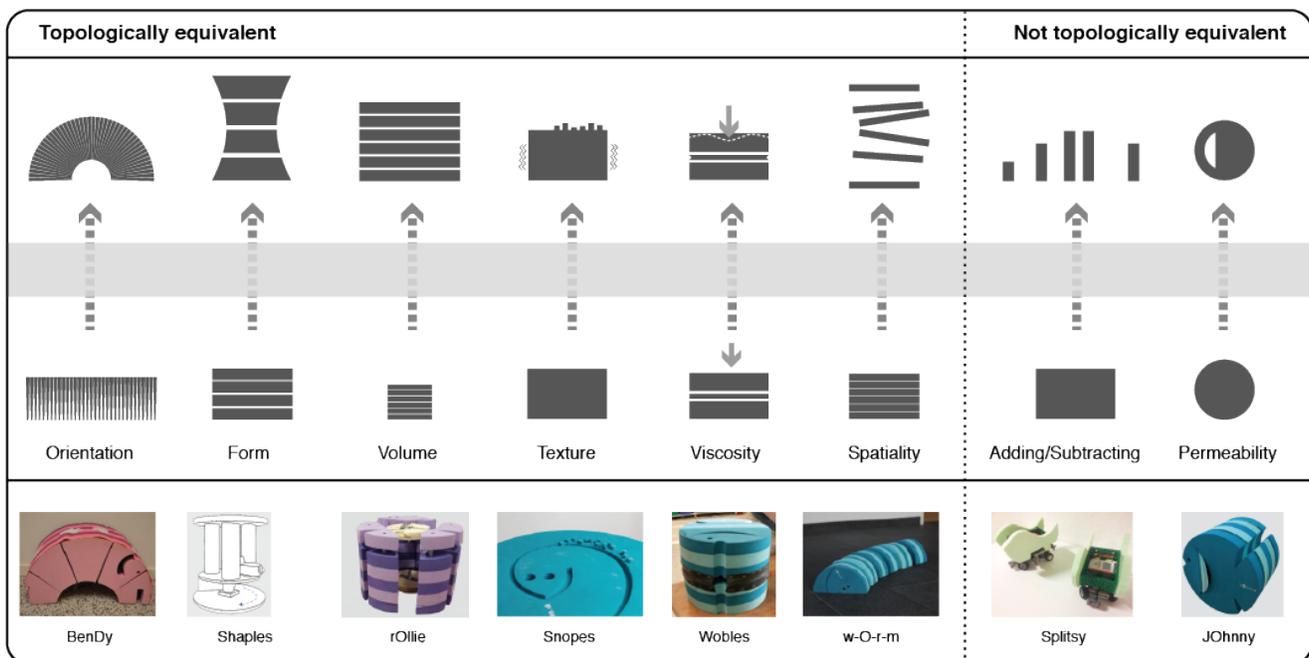


Figure 1. Overview of eight shape change sketches

making of sketches was supervised and critiqued on an on-going basis by a team of interaction designers challenging design choices and the qualities derived from these. Materials in addition to the foam objects included an array of actuators (linear, servos, stepper motors, lights, fans, bubble machine, vibro-tactile actuators, etc.), sensors (pressure, light, proximity, sound, etc.), which could be controlled using Arduino microprocessor boards.

without physically touching the object. Depending on the aggressiveness of the wand movement benDy interprets the wand interaction as soft or hard taps on the back.

Construction

Movement of the individual pieces were made possible using wires and servo-motors, and adding a thin layer of foam to the 'back' of the body letting the individual pieces separate from each other without completely falling apart.

Shaples (Form)

The Shaples design is a remake of the cylindrical tumbling object called 'Worm', and explores how change in form can inspire imagination and movement in children.

Interaction

When one interacts with Shaples in a rough manner the object grows in a twisted upward direction, which effects how it—for example—rolls on the floor or can be used for balancing. When a gentle or pause in interaction follows, the object slowly retracts into the original form and scale.

Construction

The sketch uses 12V motors, accelerometer, rubber foam and elastic fabric to enable a twisted and growing movement during interaction.

rOllie (Volume)

rOllie is a redesign of the cylindrical tumbling object called 'Fish', and explores how change in volume can inspire imagination and movement in children.

Interaction

rOllie increases in volume when rolled on the floor, mimicking the behaviour of a snowball being rolled as shown in Figure 2. To decrease volume, the user pads the surface as if clapping the cylinder back into its original shape. A microphone placed inside the cylinder registers different patterns of padding, making it possible to shrink the volume according to, for example, how hard the cylinder is being clapped or with what frequency.

Construction

The shape change is enabled by the use of a linear actuator that pushes the top part of rOllie away from the body of the cylinder. Extendable arms that project the force from the actuator towards the sides of the cylinder, make the sides expand, achieving an overall increase of volume. An accelerometer senses the orientation of cylinder and determines if rOllie is being rolled, so that the actuators can increase its volume accordingly.



Figure 2. rOllie interaction

SnOpes (Texture)

SnOpes is a redesign of a cylindrical tumbling object called 'Worm', and explores how textural changes can inspire movement and imagination in children.

The design focus on three different aspects of textural change, first, the quality or type of texture (for example spiky or bumpy) secondly, the speed or quality of movement with which one texture changes into another. Thirdly, how vibration can be used to give an impression of textural changes in a surface material (for example, how a heartbeat can be sensed as a slight change of surface texture).

Interaction

A quick movement towards SnOpes results in the hairs being pushed out fast, a slow movement makes the hairs come out slowly, or not at all. Padding and stroking SnOpes will result in the hairs being withdrawn into the body of the cylinder and subtle vibrations resembling how a cat purrs in pleasure.

Construction

SnOpes is equipped with a small camera that senses if someone reaches out to touch it, and a motor that pushes or withdraws tube-like 'hairs' from incisions in the surface. The hairs are made of the same foam material as the rest of the design, and are the size of ordinary pencils.

Wobles (Viscosity)

Wobles is a cylindrical interface based on the tumbling object 'Fish' and explores the use of change in viscosity to inspire imagination and movement in children.

Interaction

Mimicking the qualities of non-newtonian fluids it hardens when treated rough, and softens and takes on a more 'loose' form, when treated gently.

Construction

Experimenting with different material like oobleck (corn starch and water), springs, magnetorheological fluids and (both ordinary and electro-) magnets, we discovered some challenges for the constructing materials. The experiment presented here is purely speculative, since it builds on a material that makes it possible to control change in viscosity. Like ferromagnetic fluids [19] Wobles can also be actuated and make it change shape in response to upcoming attempts to interact with it physically.

w-O-r-m (Spatiality)

w-O-r-m is a redesign of the cylindrical tumbling object called 'Worm', and explores the use of change in spatiality to inspire imagination and movement in children. Using only half of the cylinder (an elongated D-shape) and dividing this into six slices the designers used stop motion film to experiment with different ways w-O-r-m could use change in spatiality to communicate.

Interaction

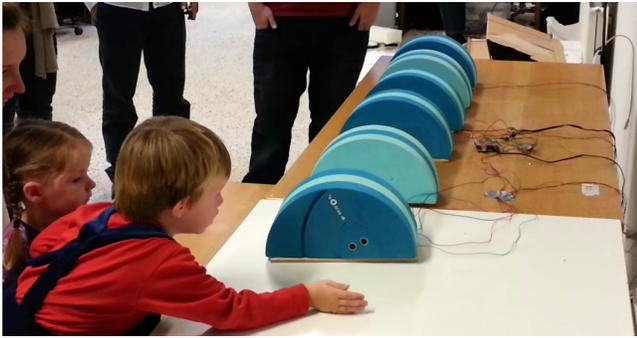


Figure 3. Approaching the eyes of the worm, makes it contract

w-O-r-m reacts to an approaching movement by springing slightly open (separating its parts) to invite remodelling of the pieces, or retract towards the centre piece if the approaching body is too fast. The immediate experience of seeing w-O-r-m in action resembles an earthworm in the way the body slowly extends from or retracts towards the centre of the body.

Construction

The design consists of six D-shaped slices as shown in Figure 3 connected with wires attached to servo motors. A ping sensor mounted in the eye-like incisions in the end of the outermost slice detects if someone is approaching, and an Arduino board controls how the individual slices either separate into a slightly open position (if the slices are not spatially apart) or starts collecting the slices towards the centre (if the slices are apart).

Splitsy (Adding/subtracting)

Splitsy is based on a drop-shaped tumbling object called ‘Whale’, and explores how to use adding and subtracting matter as a way to inspire imagination and movement in children. The design is speculative in the way that it makes use of a material that is not yet available.

Interaction

Splitsy simulates the natural movement of a school of fish when it moves over the floor as one mass and separates into smaller groups each time it meets an obstacle. The difference is that smaller groups of Splitsy parts do not automatically find their way back to the rest of the group when the obstacle is out of the way. Accordingly, one or more users must herd the groups back together by using their bodies as movable obstacles. This unpredictable behaviour is proposed as a way to invite engagement and to challenge the intended child user.

Construction

In want for a material that easily splits up and grows back together seamlessly, a crude prototype of Lego Mindstorm NXT equipped with magnets was used to explore the feel of herding pieces together.

jOhnny (Permeability)

jOhnny is a redesign of the tumbling object called ‘Fish’, and explores the use of changing permeability to inspire imagination and movement in children.

The shape of the object is almost cylindrical, and on the flat top and bottom surfaces are small incisions and holes that resemble gills and eyes.

Interaction

The gills moves constantly in a rhythm that resembles breathing. When pressing on or covering a gill, it will respond by pushing back into the hand as if struggling to breathe. After being uncovered again the gill will speed up as if in panic before calming down and returning to the initial rhythm. An accelerometer detects the orientation of jOhnny, which give rise to various interaction possibilities.

Construction

The designers placed a pair of servos inside the body of the cylinder, and attached these to thin D-shapes layers of foam over the gills. Inspired by Fukuda et al. [9] the pushing and pulling motion of the servo that controls the movement of the gills was randomized in order to add variation in the movement between open and closed gills.

Sensors detect jOhnny’s orientation, whether the eyes are covered or the body or gills are being squeezed. This allows for various playful interactions, such as stopping the gill movements entirely by covering them, and starting the movements again with CPR-like thrusts to the body as shown in Figure 4.



Figure 4. three stages of panic - from left: jOhnny blinded (and in darkness), on the side (reactivation) and upside down.

Above, we have presented the eight sketches that each explore the use of shape change to inspire imagination and movement in children.

Below, we reflect on areas of interest for designers working with shape change and electronics, and map out some initial inspirations and insights that we derived from our experimentation. These areas relate to understanding and describing some of the interaction qualities of shape changing toys, and what we call ‘*imagined physics*’.

DISCUSSION

The findings presented in the following sections, are based both upon the students’ insights, as well as the teachers’ reflections. The experimental sketches point to several interesting things about the use of shape change in interactive design. The following topics raised in this discussion, are all concerns or questions derived from practical experimentation with the subject. However, they should merely be seen as ponderings and directions for

further studies. Furthermore it should by no means be seen as a concrete recipe for how to do design that successfully utilizes the change of shape to inspire movement and imagination.

In the following we use our findings to elaborate on the framework for shape changing interfaces presented in [31]. Further, we discuss our findings related to the use of actuator properties in design, to the interaction relationship between child and object, to the temporality of the interaction, and to what we identify as ‘imagined physics’ as a resource for engaging interaction design. We use these discussions to point towards further investigations.

Elaborating the understanding of interaction with shape-changing interfaces

The framework Rasmussen et al [31] distinguishes between three approaches to interacting with shape changing interfaces; no interaction, indirect interaction and direct interaction. All the above cases represent some form of direct interaction with the objects, but vary in the way that they enter into the interaction. Fostered by the intention to explore the design space in breadth, the cases also span a wide range of approaches to direct interaction and in this way, they serve to refine the framework accordingly.

Interaction by invitation

w-O-r-m points to the potential of shape changing interfaces to invite for interaction. As the child approach the objects it expands to give an indication of how it can be manipulated. It starts out the interaction so to speak and in this way invites the child to further expand and investigate with the object along the dimension just presented. Most of the other examples starts out with human action and the objects responding in different ways

Interaction by augmenting or amplifying human action

BenDy on the other hand magnifies the powers of the child in that when the object is clapped hard, it collapses to lay flat on the floor. In this case it resembles giving the child superpowers so to speak, in the way it reacts on child’s clap. Rollie, in a slightly different way, enforces the power of rolling the object on the floor through growing, resembling a snowball effect.

Interaction by mimicking and counter-mimicking action

Snopes responds to the human reaching out through also reaching out with its texture. The objects’ range of out-reach mirror the human range. Small human movements result in small product movements and vice-versa. Johnny on the other hand represents a counter-mimicking approach to human action. As the fish’s gills are pressed it seeks to open them up.

Metaphors of interaction

The range of examples presented also illustrates a very rich use of metaphors in the interaction. This is in part due to the domain of play objects, which resemble stylized animals. It is interesting however, that even though the cases in this way have the same starting point, a rich set of metaphors

are being applied ranging from ‘magic material’ in Wobles, which hardens the more actively it is played with, to the snowball effect of rOllie to the range of zoomorphic effects also pointed out the Rasmussen et al [31] and as seen in the cases of Snopes with its subtle vibrations mimicking a cat purring, Johnny with its gills constantly moving in a rhythm resembling breathing, and wOrm’s worm-like extensions of its body-length.

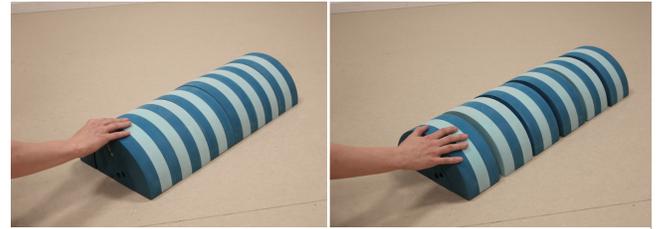


Figure 5. the w-O-r-m splits slightly apart, signaling that the pieces can be moved.

Revealing responsive treatments (clues of use)

Finally, an inherent quality of all the cases, except wOrm and BenDy, is that their responsive treatments, i.e. the way they should be treated to trigger shape-change is not immediately revealed. Although BenDy provides a very direct cue through handprints on the back of the elephant to show the child that here is an active ‘area’. wOrm reveals its direction of movement as the child approaches the object. However all the others present the object itself for the children to explore its dynamics through manipulation. E.g. rOllie must be rolled (although the name provides a cue) whereas similar forms in the cases of Shaples which deforms in response to rough treatment and Wobles, which changes its viscosity hardening at rough play shows very different behaviours. The lack of revealing the responsive treatments contributes to the playfulness of these objects. In less playful application areas this is not necessarily an appropriate quality. But the cases illustrate the huge potential of shape changing interfaces in only gradually revealing their responsiveness as the technology can be totally hidden and only through interaction reveal its existence. This could be both a strength or a weakness depending on the area of application.

Using actuator properties as a design resource

Actuators, such as electrical motors or hydraulic pistons, have properties that are obviously useful, but also many overlooked ones. Obviously, their use is to move some part of a design in a controlled manner, but in doing so, they make mechanical noises that could either work for your design or against it. Further, they do not make the same noises, and should thus be utilized carefully. Some sounds angry—almost like wasps—whereas others have a cosy sound like a cat purring in a sofa, so the choice and combination of actuators are quite central to the soundscape of a design. This can be designed into the peripheral awareness as the careful crafting of an electric train’s propulsion motor, or brought to the forefront as artists have done with various examples including playing tunes with

computer peripherals, stepper motors, and have even subverted industrial robot movements into musical instruments [32].

During our experiment the critical role of the aesthetics of sound was made clear with a number of the sketches. For example, the initial impression of Shaples was a sturdy motorized robot rather than a playful tumbling object because of loud mechanical noises from the actuators, and the magical feel of Splitsy pieces separating and joining silently and seamlessly was completely destroyed by the sounds of a struggling motor. In contrast, jOhnny demonstrated how the humming of the servos could support the experience of the moving gills, and how slight changes in the pitch when changing from pulling to pushing, would enhance that subtle movement.

In terms of how actuator properties effect movement, the way—for example—a linear actuator is attached to the material it is intended to move, effects the nuances of how that material moves. The use of embedded springs in arms used to push or pull, makes for a cushioned effect both visually and haptically, but also invites a user to push back to feel the tension of the spring and enjoy the feel of how it pushes back into the hand. This was demonstrated with jOhnny, where it supported the design of the gills, and in Wobles, where the feeling of springs pushing back destroyed the impression of change in viscosity.

Interaction relationship

The goal of our sketches was to inspire movement and imagination using various types of shape change. Although, we did not conduct user studies, we still venture to speculate on the interaction relationship between the shape-changing objects and their potential users.

In order to invite users to engage in physical interaction, w-O-r-m- used subtle movements prior to the physical contact between human and object with great success. The object's pieces would spring slightly apart if approached, achieving the effect of a welcoming gesture, signalling 'my pieces can move' as shown in Figure 5. In contrast, Shaples achieved a slightly hostile effect by using aggressive sounding motors to expand the body rapidly after being touched. In effect, people touching it would quickly pull back their hand. Whereas w-O-r-m would invite, Shaples would dismiss a user.

A number of sketches from the experiment touch on the difference between the object being (seemingly) self-

actuated and the object being directly manipulated by the user. For example, rOllie reacts directly to the rolling movements made by the user and maps these movements precisely with its growing body. Splitsy, on the other hand, splits up and change direction when encountering objects on its own. The effect is that the relation between rOllie and a child is a relatively simple slave-master relationship because the child is in charge of the interaction, whereas the relationship between Splitsy and a child is more equal since they both can initiate actions.

Using various sensor technologies designers can open for the possibility to create a new relationship between child and object because a self actuated object takes on an agent that can contribute to the interaction on its own, whereas an object that can only be directly manipulated seems to contribute to the interaction on a lower level. The relationship between child and an object that can actuate itself is simply more even than between a child and an object that has to be changed by the child.

Temporality

Time and temporality of interaction is another area that the experiment inspires to explore. The slowly growing 'hairs' of Snopes suggests a different temporality than the immediate feel of change that Wobles provide.

Related to temporality is response time as in the time between input and output. It is an interaction attribute that has already been touched upon by [22] and which in our experiment is perhaps most interesting in terms of the introduction of the wand to the benDy design. Moving away from direct manipulation of the shape of benDy and introducing a wand as a mediator the designers open up for slight delays in feedback, and other qualities of the feedback that are less 'natural'. For example, a child might make a series of wild gestures with the wand and then 'send' the magical instruction to the object with a firm gesture directed towards its back. As a result benDy would then react to the entire series of gestures by orienting its body parts in a certain composition. Using digital technology would allow for the possibility to control when the response should occur, something that would make it possible to do a long series of gestures—which might be fun in itself—and then 'send' it to the object which could then interpret or simply repeat the movements. Delayed response is not very common when handling physical objects, so controlled and delayed feedback might make for an almost magical experience.

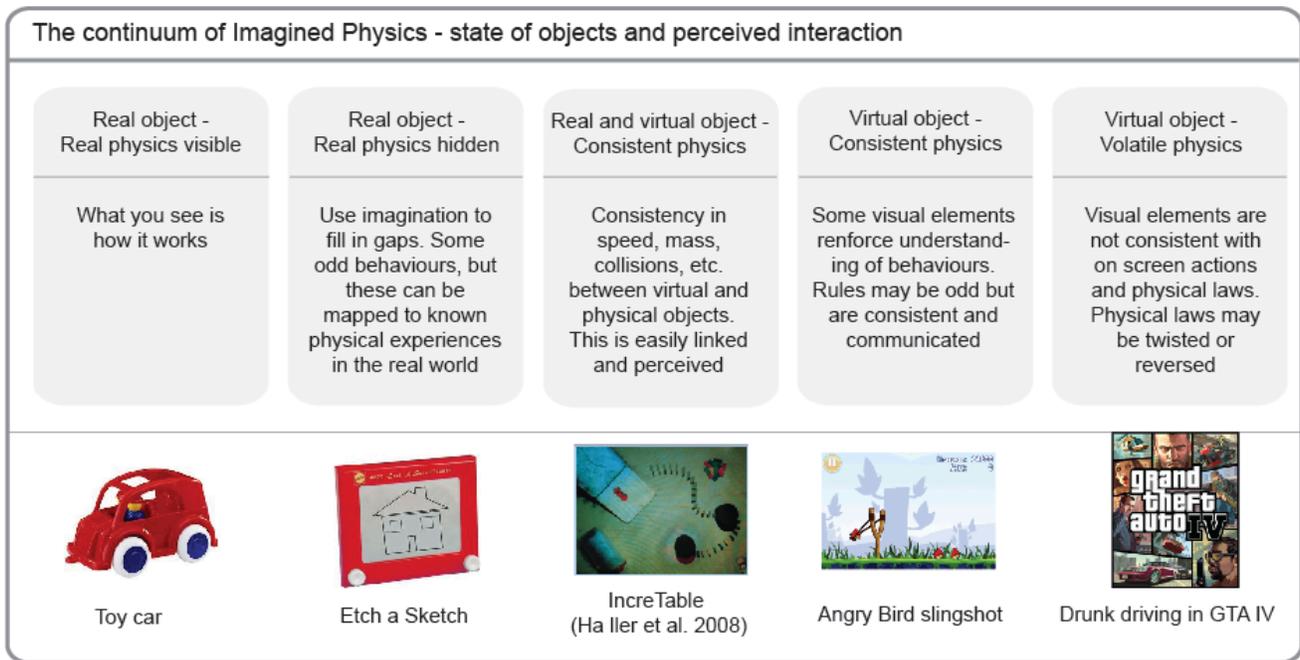


Figure 6. Examples and interaction along the Continuum of Imagined Physics

We now take a step back and examine the curious nature of interaction with shape-changing objects with specific focus on the perceived laws of physics that are followed—or not followed from the perspective of the user.

Real and imagined physics

The work presented above suggests how the sketches are in one sense tied to their physical form, yet—through the use of actuators, sensors, and computer algorithms—can behave in ways that are surprising, unpredictable and that might even be perceived as magical. While the present paper does not evaluate user responses to the redesigned tumbling objects, the concept sketches enable the designers to try different behaviour mappings, input modes and transitions, and go beyond traditional physics to an imaginary world of other rules. We call this phenomenon ‘*imagined physics*’ in want for better words. Adding imagined physics to real physics presumably gives rise to new experiences that are initially tied to metaphors based on real physics. For example, rolling rOllie results in volume growth just as when rolling a snowball, whereas the patting used to reduce the rOllie’s size, does not draw on either familiar physics or hold a connection to the physical properties of snow and snowballs. However, it is quite similar to the physical and virtual elements discussed in [1] with the physical toy duck that follows the user’s hand keeping a consistent distance thus leading the user to imagine an invisible leash. In the case of the rOllie sketch, the interaction does not entirely build on our experience from real world physics, the patting to reduce size-interaction seems plausible and easily understood, however the user must fill in what is not made visible in the materials.

The *imagined physics* can borrow from metaphors in shape and nature. In the zoomorphic examples the child is invited to learn the “personality” of the object, for example, the worm utilized sensors that look like eyes, and the behaviour drawing away from the approaching hand gives the impression of managing its personal space. This design’s connection between the cause and effect is rather simple, and is suggested through cues found in living things. When we move away from these cues and instead map user input/actions to shape change behaviours we find examples that could be explained through imagined physical phenomenon. Shaples, for example, changes between two form states depending on the roughness of handling. Like with the Etch a Sketch drawing toy that hides the sand that enable erasing the drawing, a child will quickly learn to interact with the product though the this mapping is not explicitly signalled. For some of the sketches, real physics are manipulated and managed in ways not possible to mimic with physical objects. For example, Wobles involved the “programmed” viscosity of the object, in this case mapping the roughness of handling to firmness, however—since Wobles does not make use or ‘real’ physics, that connection could have been tied to any input.

As a preliminary step in explaining this concept, we provide a continuum shown in Figure 6. With a series of examples, the figure presents an overview of how interaction can be perceived in various ways. The examples range from physical objects with physics that are visible, consistent, and easy to understand, over mixed systems, which involve physical and virtual elements with behaviours that traverse the embodiments, to virtual systems that are unpredictable, volatile, and include behaviors that seem to change without causality and that would require intense imagination if not

to cause complete confusion. While some games vary the

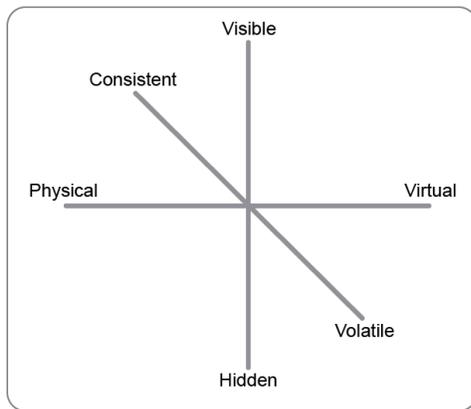


Figure 7. Design space of Imagined physics as three dimensional space

physics of collisions, gravity, friction, etc. in successive levels, one example of virtual elements with volatile behaviour is the drunk driving mode in the Grand Theft Auto IV videogame..

In taking a step back, it seems that the range of objects could be placed in a three dimensional design space as shown in Figure 7 with axes describing the material and interactive features *physical/virtual*, *volatile/consistent*, and *visible/hidden*. Objects could involve physical or virtual elements—or a combination as in InceTables [21]. The rules of physics could be consistent and predictable or volatile (changing erratically). The third dimension deals with causality—the rules of physics can be shown to the user and made visible through form elements as is the case with a bicycle chain and sprocket, or they can be hidden as is the case with “black box” technologies that hide the mechanics of physical behaviors.

More in depth analysis of interactive systems according to these diagrams will likely lead to refinements of the models—we hope this future work will also inform the design of inspiring shape changing objects. For example, it may be difficult to consider an object that is mainly physical, with visible mechanics enabling the shape change yet that are volatile in their behaviors. The sketch Splitsy, if made according to the designers’ vision of using programmable matter, could be such a system.

The concept of imagined physics is interesting because it treads on HCI territory that may conflict or seem at odds with expected form language and interface affordances. With objects embedded with “imagined physics” it is unclear how much the user will continue to explore and try to find new connections between their behaviour and the shape changing object’s behaviour unless it is suggested in some way. In game design, for example, the length of the experience is suggested as an estimated play time on the casing, but in games clear goals are often achieved along the way to signal the progression, which help a user stay engaged in the exploration of the game. In hypertext fiction

research, studies suggest that users explore for some time, but quickly change their focus toward “getting the gist” of the story [24]. In those studies, users were faced with obstacles and unexpected behaviours of the storyworld controlled by the computer system. At first, users would explore and look for variation; however, there was a rather quick shift toward making sense of the story that all users shared. Given playful shape changing objects that can change shape according to mappings that may change and may not adhere to ‘real’ physics, it would be interesting future work to evaluate whether users want continued and surprising imagined physics, or do they strive to develop an understanding of the general behaviour of the object—if this understanding of how things work is upset by changes, how tolerant are the users or does it draw them in even more?

Using the framework as a generative tool for design

Rasmussen et al [31] presented their framework after having studied a wide range of existing shape-changing interfaces. In this paper we report on an experiment where we used the distinctions provided by the framework generatively, to map out a breadth in the design space of a shape-changing playful objects for children. The range of solutions indicates that the framework also has some generative powers. Even though, for the sake of the experiment, we wanted to pursue the types of shape change one-by-one, in more natural design cases, this would probably not be a fruitful approach. However, systematically trying out alternatives, inspired by the breadth of the design space as illustrated by the framework seems to be a very fruitful approach to more diverse and rich shape-changing interfaces. In this experiment, we only looked into varying types of shape change. The framework also maps out different forms of transformation, the combination of these with the types of shape change signals interesting future work. The present work suggests additional areas for expanding the framework and points toward expanding the notion of interaction with shape-changing objects.

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